Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6180--95-7785

Preliminary Evaluation of High Expansion Foam Systems for Shipboard Applications

E. K. Budnick
E.W. Forssell
G.G. Back III
R.L. Willard
R.J. Ouellette

Hughes Associates, Inc.
Baltimore, MD

J.T. Leonard

Navy Technology Center for Safety and Survivability
Chemistry Division

November 27, 1995

Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 27, 1995	(3/91-10/91)

4. TITLE AND SUBTITLE

Preliminary Evaluation of High Expansion Foam Systems for Shipboard Applications

5. FUNDING NUMBERS

63514N/S1565-SL

6. AUTHOR(S)

E.K. Budnick*, E.W. Forssell*, G.G. Back III*, R.L. Willard*, R.J. Ouellette* and Joseph T. Leonard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6180--95-7785

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Sea Systems Command
Washington, DC 20362-5101

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Hughes Associates, Inc. Baltimore, MD 21227

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT *(Maximum 200 words)*

A preliminary evaluation was conducted on the feasibility of protecting shipboard spaces with high expansion foam systems. Two series of tests were conducted on the effectiveness of high expansion foam on intense Class A and B fires under conditions similar to those found in shipboard spaces. A number of areas requiring further study were also identified.

This investigation demonstrated that high expansion foam can be an effective fire suppression agent in shipboard fire scenarios. However, additional work is needed in the areas of compartment access, foam removal and cleanup, application rates, foam properties and venting of air displaced by the foam. These topics should be addressed in full-scale shipboard tests.

14. SUBJECT TERMS

High expansion foam
Foam systems

15. NUMBER OF PAGES

66

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

FIGURES

FIGURES (continued)

FIGURES (continued)

PRELIMINARY EVALUATION OF HIGH EXPANSION FOAM SYSTEMS FOR SHIPBOARD APPLICATIONS

1.0 INTRODUCTION

A select group of fire extinguishing agents has long been employed in the protection of areas where access is limited and/or water damage caused by sprinklers is not acceptable. The fire protection Halons together with carbon dioxide, high expansion foams and some dry chemicals make up this group. With the future of the Halons diminished by their link to stratospheric ozone depletion, high expansion foam is receiving greater attention. This is of particular interest in providing military shipboard fire protection where Halon systems are extensively used.

2.0 BACKGROUND

One of the driving forces behind the development of high expansion foam was the desire to remotely fight fires in mine shafts. Gaining access to fight mine shaft fires is an extremely risky undertaking due to toxic exhaust gases from the fire and damage to ceiling supports by the fire. Flooding the shaft with a high expansion foam from the surface is effective and eliminates the need to enter the damaged shaft [1,2].

2.1 Fire Performance

High expansion foam has three effects on a fire. The first and most important effect is the reduction of the amount of air reaching the fire. This is accomplished by both displacing air in the space around the fire and by forming a barrier between the surrounding environment and the fire. The fire is smothered by the foam when sufficient amounts reach the fire. Second, the foam also acts as an insulator, reducing the amount of feedback radiation the fire receives from its surroundings. The third effect is a cooling effect caused by the absorption of heat by the foam as it breaks down and its liquid content is vaporized or deposited. However, as the liquid content of the foam is small, this effect is small as well.

High expansion foam has been shown to be effective against both Class A and Class B fires [1-8]. One of its main advantages is that it is able to flow around or over objects to reach a fire.

2.2 Foam Properties

The physical properties of a high expansion foam determine the effectiveness of the foam in a specific fire scenario. The two most important properties are its stability as reflected in its drainage rate and its expansion ratio.

Manuscript approved October 5, 1995.

2.2.1 Drainage Rate

The drainage rate is the rate of liquid loss from the foam. The liquid draining from the foam reduces the thickness and strength of the bubble walls that make up the foam. As drainage progresses, the foam becomes more fragile and less able to endure high temperature environments. This results in an increased breakdown rate of the foam [8,9]. In order for the foam to advance on a fire, the breakdown rate must be less than the application rate. Therefore, a lower drainage rate will make a foam more effective.

The drainage rate also has an effect on the flow properties of the foam. As liquid drains from the foam, the density of the foam is reduced causing the foam to become less fluid and harder to project toward a fire [8,9].

2.2.2 Expansion Ratios

The expansion ratio is the ratio of the volume of the foam to that of the liquid used in making the foam. It, therefore, determines the density of the foam and has a significant influence on the viscosity of the foam. While lower expansion ratio foams use more liquid to flood the same volume, they are easier to project down a corridor [8,9]. The lower expansion ratio foams are also able to endure a greater heat flux or thermal exposure [10].

High expansion foam is generally considered to have an expansion ratio in the range between 200:1 and 1000:1 [3,9]. For comparison, low expansion foams like AFFF have expansion ratios between 2:1 and 20:1 with AFFF normally used with an expansion ratio of 8:1 [9].

2.3 Generation of High Expansion Foam

The generation of high expansion foam can be broken down into three steps. The first step is the mixing of the foam concentrate with water. This is generally done with an eductor which takes advantage of the water flow to both draw and mix the foam concentrate in most portable systems as well as some fixed systems. Concentrate pumps with ratio controllers are used to draw and mix the foam concentrate with water in large capacity fixed systems. In high expansion foam, the concentrate is mixed with water to make a 1.5% to 2% concentrate mixture [9]. In the second step, the mixed solution is sprayed from a nozzle onto a screen. Air is then blown through the screen to make the foam. The spray leaving the nozzle can be relied on to entrain sufficient amounts of air to generate the foam, or a fan or blower can be used. A fan or blower must be used to obtain foams with expansion ratios above 250:1 [9].

2.4 Advantages and Disadvantages of Hi-Ex Foam

High expansion foam has several advantages and disadvantages over other types of fire protection agents. Some of these have already been discussed -- the ability to remotely fight a fire and the ability to extinguish guarded or obstructed fires. Other significant advantages or

disadvantages lie in the areas of cleanup after extinguishment, damage to immersed equipment, air supply requirements, and access to the flooded compartment.

2.4.1 Cleanup of Compartment

The cleanup of the compartment after the extinguishment of the fire by flooding with high expansion foam amounts to mopping or wiping up the liquid that drained out of the foam as it broke down [11]. The amount of liquid deposited can be reduced by blowing the foam out of the compartment before it breaks down completely. While this is more cleanup than that required after a Halon discharge, it is much less than that required after deluge sprinkler activation or dry chemical use.

2.4.2 Damage to Immersed Equipment

The damage to equipment caused by immersion in high expansion foam mainly consists of limited water damage. This is caused by the liquid deposited on the equipment due to drainage and the break down of the foam. This damage is limited due to the low water content of the foam by volume. Tests have been done on both cardboard boxes stacked on pallets [8] and operating electrical equipment [11] immersed in high expansion foam for several hours.

In the tests with cardboard boxes, it was found that only slight damage occurred to the cardboard boxes unless a large amount of foam remained on top of the boxes for an extended period. When the pallets were arranged in a normal rack storage array, only a superficial dampening occurred even after being immersed on two successive days with no attempt to remove the foam. In any case, the contents of the boxes were not damaged [8].

In the tests on operating electrical equipment, some of the glass tubes in the equipment were found to have been broken after a few minutes. This was believed to have been caused by arcing between pins facilitated by moisture from the foam. The larger glass tubes were unaffected. After replacement of the damaged parts the equipment operated normally. Two of the original five items had no damage, even after being immersed overnight [11].

2.4.3 Compartment Access While Flooded

Access to a compartment while flooded with high expansion foam is severely limited. The foam is known to cause severe disorientation due to the lack of visibility. High expansion foam also causes some breathing discomfort even though there is still adequate breathable air in the foam. This breathing discomfort also heightens the disorientating effect [3,7,9,12,13].

Communication with people immersed in high expansion foam is also severely limited due to the absorption of both sound and radio waves by the foam. Tests have shown that walkie talkies were unable to reach people immersed in high expansion foam even though the distance between the radios was small, approximately 4.4 m (14 ft) [7]. Shouting was also ineffective [7].

Immersion in the foam can cause the regulator valve of on demand type self-contained breathing apparatus to stick open [9,14]. Therefore, this type of breathing apparatus should not be used.

Some components of the foam concentrate are reported to cause irritation of the skin and eyes on contact [15,16], and inhalation of the vapors of these same components has been reported to cause nose and throat irritation [15,16].

2.4.4 Air Supply Requirements

A further disadvantage of high expansion foam is that a fresh air supply is needed. Products of combustion, particularly incomplete combustion, in the air supply of high expansion foam generators have been shown to severely hamper the production of foam and to cause the foam produced to be fragile [17]. This is not that much of a problem for portable systems as they draw their air near the floor. Fixed systems, on the other hand, will have to have a fresh air supply connected to them from outside the space or have an air cleaning system attached [18].

3.0 SHIPBOARD APPLICATION

Both fixed and portable systems would appear suitable for the protection of shipboard spaces. Larger spaces (main and auxiliary machinery spaces, storerooms, etc.) would use high capacity fixed systems. Portable systems could be used to protect smaller spaces.

3.1 Fixed Systems

Conceptually, a typical fixed high expansion foam system applied to shipboard spaces would employ several generators served by a single, remotely located, concentrate supply. The generators would be located inside the space, close to the ceiling. The concentrate supply would have both a primary and reserve capacity. A ratio controlled pump would be utilized to draw and mix the concentrate with water. The fresh air supply for the generators would come from the existing ventilation supply where possible.

For example, a fixed high expansion foam system applied to an engine room of a CG 47 class cruiser would employ four high expansion generators. Each of these generators would have a capacity of 170 m^3/min (6000 CFM) 600:1 expansion foam for a total foam capacity of 680 m^3/min (24000 CFM). This is a high enough capacity to flood the approximately 1700 m^3 (60,000 ft^3) engine room [19] in the required three minutes (based upon a JP5 fuel spill as the primary hazard) with the 15% factor for compression of the foam applied as per NFPA Standard 11A [3]. The two ventilation supply fans for this space are rated for a combined 750 m^3/min (26,500 CFM) of fresh air which is enough to cover the air requirements of the generators.

In flooding this size compartment, water consumption would be approximately 280 ℓ/min (75 gpm) and foam concentrate consumption would be approximately 5.7 ℓ/min (1.5 gpm) for each generator. The total concentrate supply required for a combined primary and reserve would be approximately 140 ℓ (36 gal). This system is schematically shown in Fig. 1.

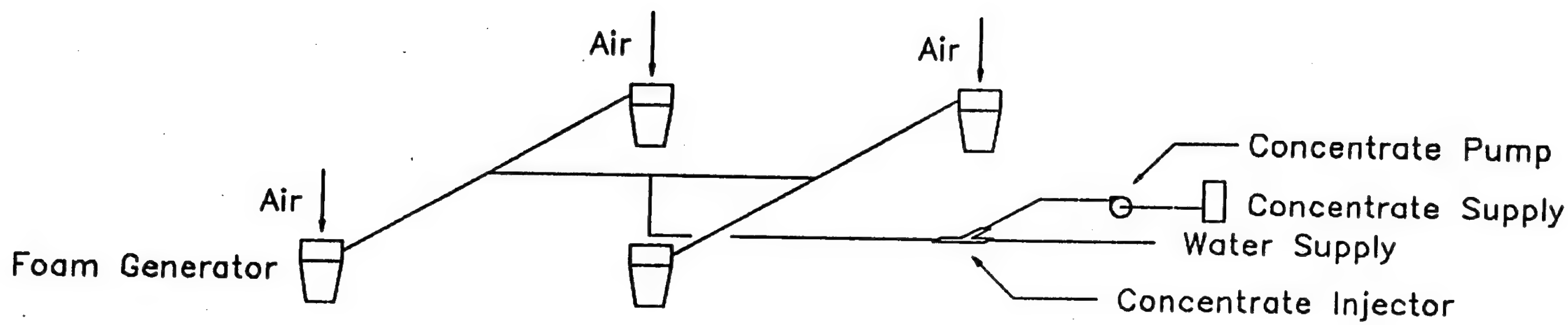

Fig. 1 — Schematic of fixed high expansion foam system

3.2 Portable Systems

The portable high expansion foam generators applicable to shipboard use are of the aspirating nozzle type (no fan). These generators generally have foam capacities between 21 m^3/min (750 CFM) and 35 m^3/min (1250 CFM) of 250:1 expansion foam. They have a deceptive weight of approximately 4.5 kg (10 lb). It is deceptive because a concentrate supply may have to be moved as well and a full 19 ℓ (5 gal) container weighs approximately 23 kg (50 lb).

These portable generators are designed to be attached to a 3.8 cm (1.5 in.) hose line and consume between 83 ℓ/min (22 gpm) and 190 ℓ/min (50 gpm) of water. The eductor and concentrate supply can be located remotely from the nozzle provided that sufficient pressure is maintained at both the nozzle and eductor.

4.0 PRELIMINARY TESTS

4.1 Purpose

The purpose of these tests was to evaluate the feasibility of using high expansion foam as a firefighting agent for use onboard ships. This evaluation was based on the cooling and extinguishing capabilities of the foam. Specifically, these tests examined the effects of flooding adjacent compartments as well as the fire compartment. This testing also provided an evaluation of difficulties encountered in handling high expansion foam, foam generating equipment and concentrate.

4.2 Test Facilities

These tests were conducted at the Chesapeake Bay Detachment of the Naval Research Laboratory. A steel enclosure divided by steel bulkheads into four compartments of equal size was used in these tests. This enclosure, shown in Fig. 2, was constructed with 0.95 cm (0.375 in) steel plates with "T" shaped beams welded vertically in the center of each wall. Each compartment in the enclosure is nominally a cube 2.4 m (8 ft) on a side with a volume of approximately 14.5 m^3 (512 ft^3). There is a 66 x 168 cm (26 x 66 in.) door opening in each compartment leading outside with the exception of the center compartment. There is a 66 x 168 cm (26 x 66 in.) door opening in the center compartment leading to both the east and west compartments. The east compartment served as the fire compartment and had an adjustable ceiling vent 1.2 m (4 ft) wide.

4.3 High Expansion Foam Generating Equipment

Two high expansion foam generators were used in these tests. The first generator, a National Foam Model GP-70, was borrowed from the College Park Volunteer Fire Station, Prince Georges County, MD. It is a gasoline engine-driven generator with a foam output of approximately 85 m^3/min (3000 CFM). Approximately, 170 ℓ/min (45 gpm) of water is consumed

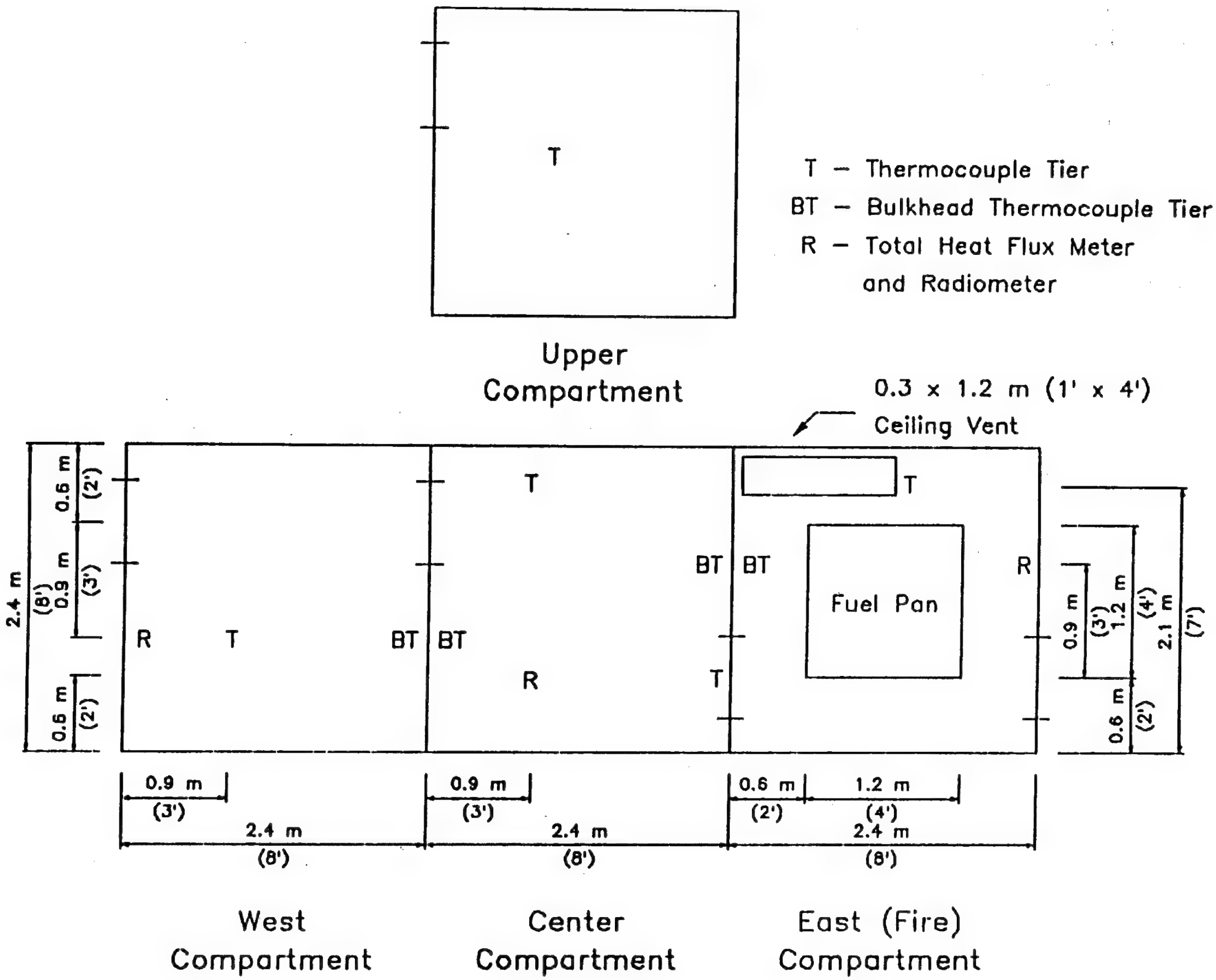

Fig. 2 — Plan view of test enclosure

along with 3.4 ℓ/min (0.9 gpm) of concentrate (2% of water consumption by volume). It produces foam with an expansion ratio of approximately 500:1.

The second generator was an MSA Mini-X-II [9]. It is a true portable high expansion foam generator in that it weighs 5.4 kg (12 lb). It produces 21 m^3/min (750 CFM) of foam with an expansion ratio of 250:1. Approximately, 83 ℓ/min (22 gpm) of water and 1.7 ℓ/min (0.44 gpm) of concentrate are consumed. This generator is of the type that relies totally on air aspirated into the generator in order to expand the foam (no fan).

4.4 High Expansion Foam Concentrate

MSA VEEFoam concentrate was used in approximately half of these tests. It is their top of the line high expansion foam concentrate. It also has the distinction of being UL listed as both a low expansion foam (expansion ratio between 5:1 and 20:1) and as a high expansion foam [9].

A "fire service" foam concentrate was used in the remaining tests. It was obtained from the College Park Volunteer Fire Department along with the 500:1 expansion generator.

4.5 Test Fires

Three types of fires were used in these tests: Class B pan, Class A, and Class B vertical spray.

4.5.1 Class B Pan Fires

In these fires, JP5 was continuously sprayed horizontally at a rate of 3.8 ℓ/min (1.0 gpm) across a 1.2 x 1.2 x 0.1 m (4 x 4 x .3 ft) pan in the fire compartment as shown in Fig. 3. This resulted in a 2.2 MW fire. The JP5 is applied by a 145° fan type Bete nozzle model FF-93145 that is fed from a pressurized fuel tank located 6.1 m (20 ft) from the enclosure. The fuel tank was rated for a capacity of 189 ℓ (50 gal). The fuel tank pressure was maintained at 690 kPag (100 psig) by connection to a regulated nitrogen cylinder. A 1.9 cm (.75 in.) globe valve was used to control the flow rate of JP5 to the fire pan with a pressure gauge used to measure the pressure at the nozzle. Three-quarter turn ball valves served as shut down and depressurization controls. All fuel controls were manually operated.

4.5.2 Class A Fires

Wood cribs, similar in construction to those used in 10-A rating fire extinguisher tests [19], were used in these fires. The number of layers was reduced from the 19 layers of 11 members to 12 layers of 11 members. This was done to keep the top of the crib at the mid-point of the door opening between the center and east compartments. The crib was placed on three 20 cm (8 in.) cinder blocks above the pan used in the Class B pan fires as shown in Fig. 4. 3.8 ℓ (1 gal) of n-heptane and 1 min operation of the Class B pan fire was used to ignite the crib.

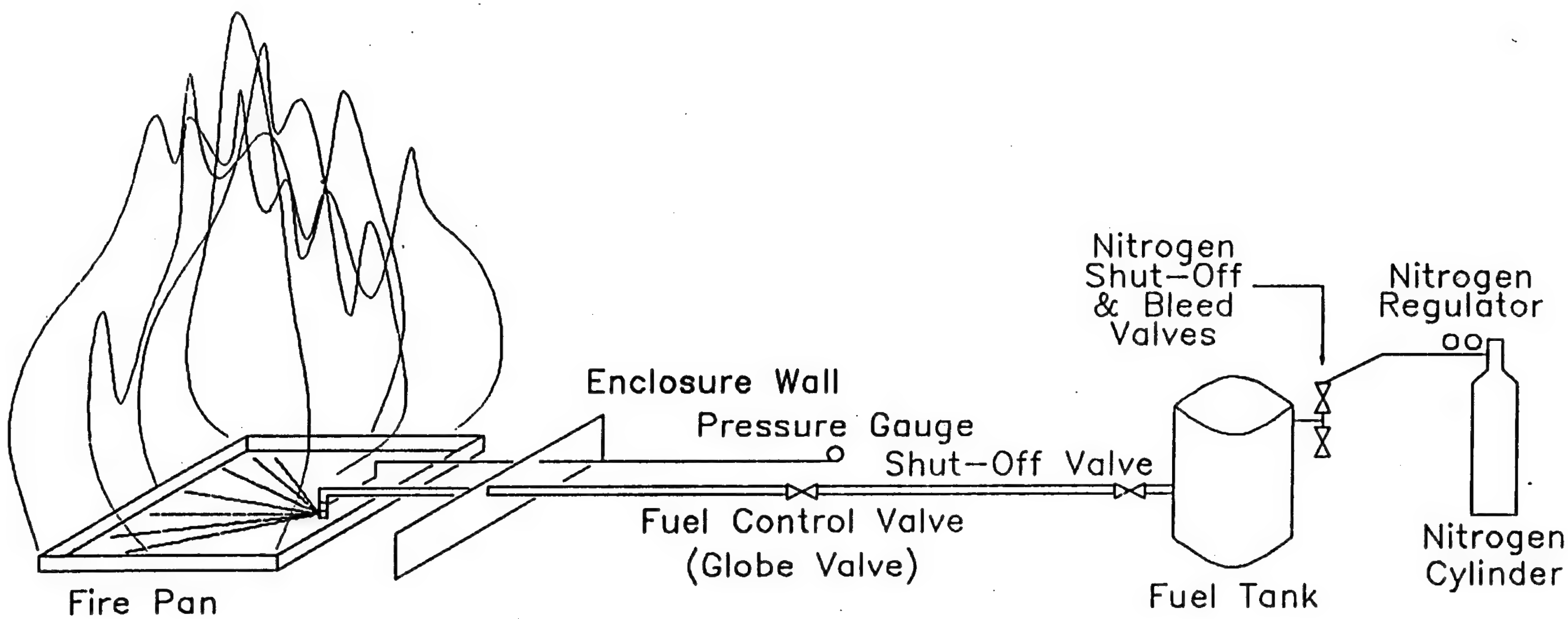

Fig. 3 – Class B pan fire

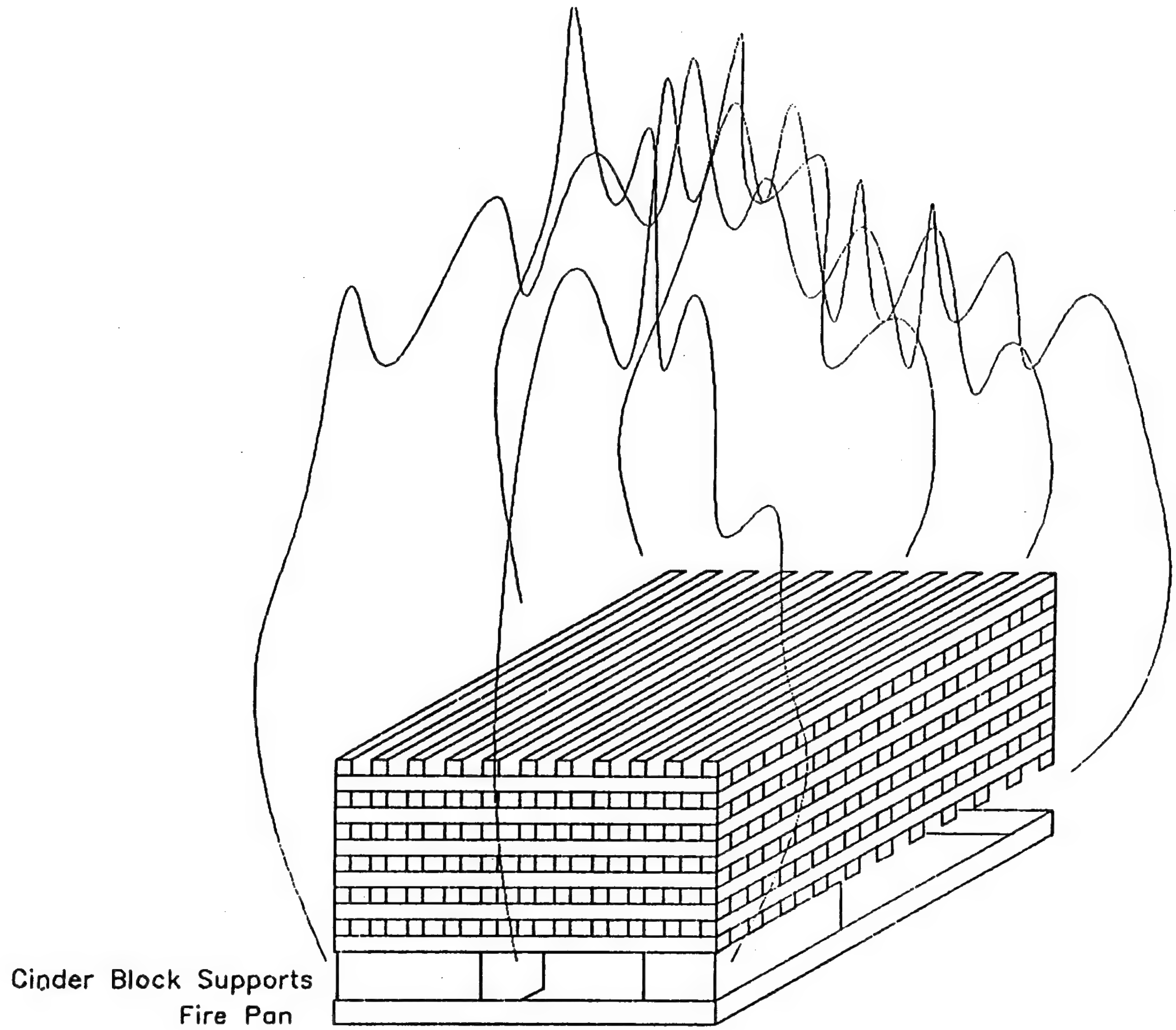

Fig. 4 — Class A wood crib fire

4.5.3 Class B Vertical Spray Fires

These fires used the same setup as the class B pan fires with the exception that the pan was removed and the nozzle was replaced as shown in Fig. 5. The replacement nozzle was a Bete model P-80 which is a fine atomizing type nozzle and was vertically oriented.

4.6 Procedure

Two series of tests were conducted. The first series focused on the extinguishing capabilities of the foam. In this series, a test was run with each of the three types of test fires (Class B pan, Class A, and Class B vertical spray) for each generator. The foam was applied at the entrance to the west compartment with all three lower compartments being flooded. The fire was in the east compartment. When the portable generator was used, the firefighter was allowed to advance on the fire to the entrance to the center compartment. The doorway between the east compartment and outside was closed. This setup is shown schematically in Fig. 6.

The second test series focused on the compartment cooling effects. Only the west and center compartments were flooded. To accomplish this, the entrance to the east compartment from the center compartment was closed off with steel plates and the entrance to the east compartment from outside was opened. The Class B vertical spray fire was used in this series. This setup is shown schematically in Fig. 7.

4.6.1 Test Sequence

1. Initiate data logging and ignite fire.
2. Allow preburn of 10 minutes (5 minutes for Class A fire to insure adequate remaining fuel).
3. Agent applied until extinguishment or until no more foam will enter enclosure (foam emerging from top of doorway as fast as entering in bottom of doorway).
4. Fuel is turned off and test is ended after fire has been extinguished or 5 minutes after start of agent application.
5. Space is prepared for next test, i.e., allowed to cool and agent removed.

4.7 Instrumentation

The instrumentation used in these tests is shown in Fig. 2.

4.7.1 Temperature

The temperature of each compartment was monitored by a vertical tier of type K glass braid thermocouples. Each tier had 8 thermocouples at 30 cm (1 ft) intervals, starting 15 cm (6 in.) from the ceiling of the compartment.

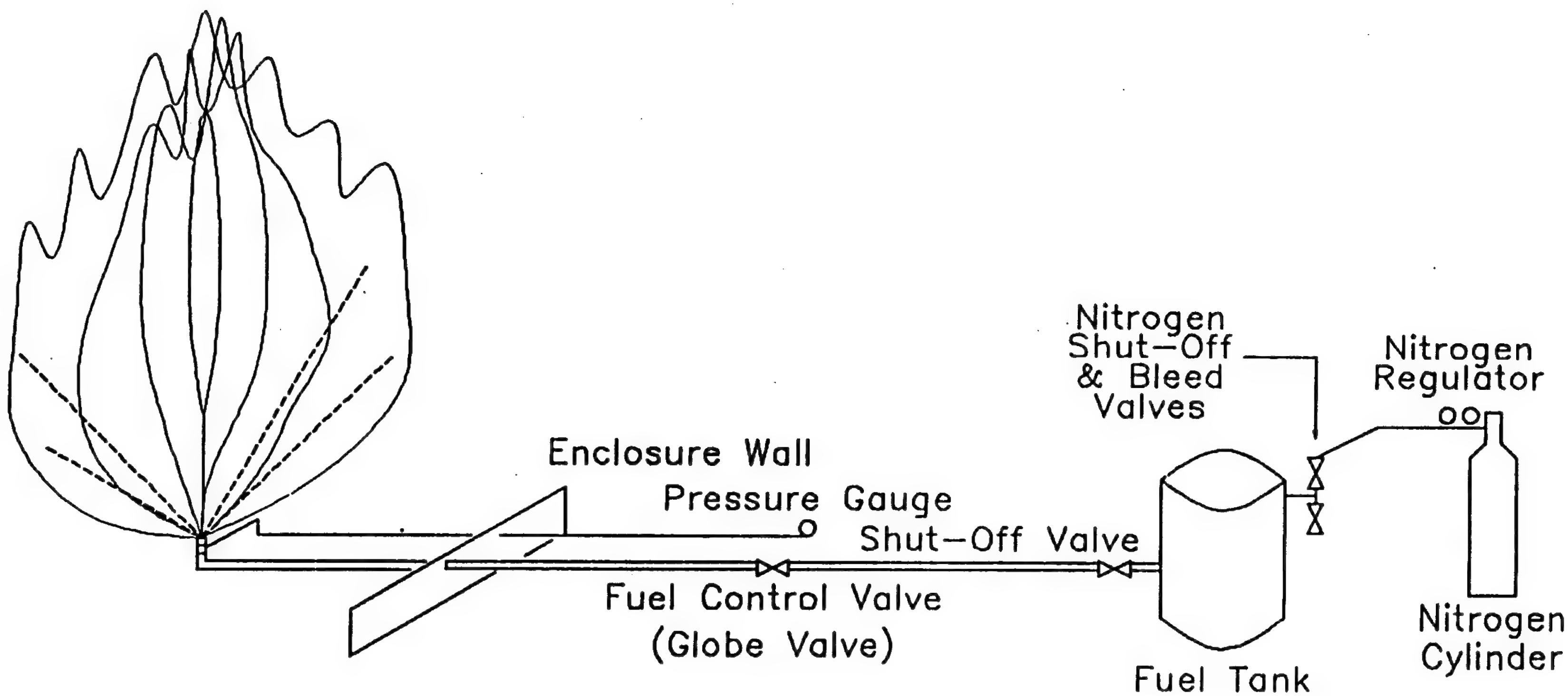

Fig. 5 – Class B vertical spray fire

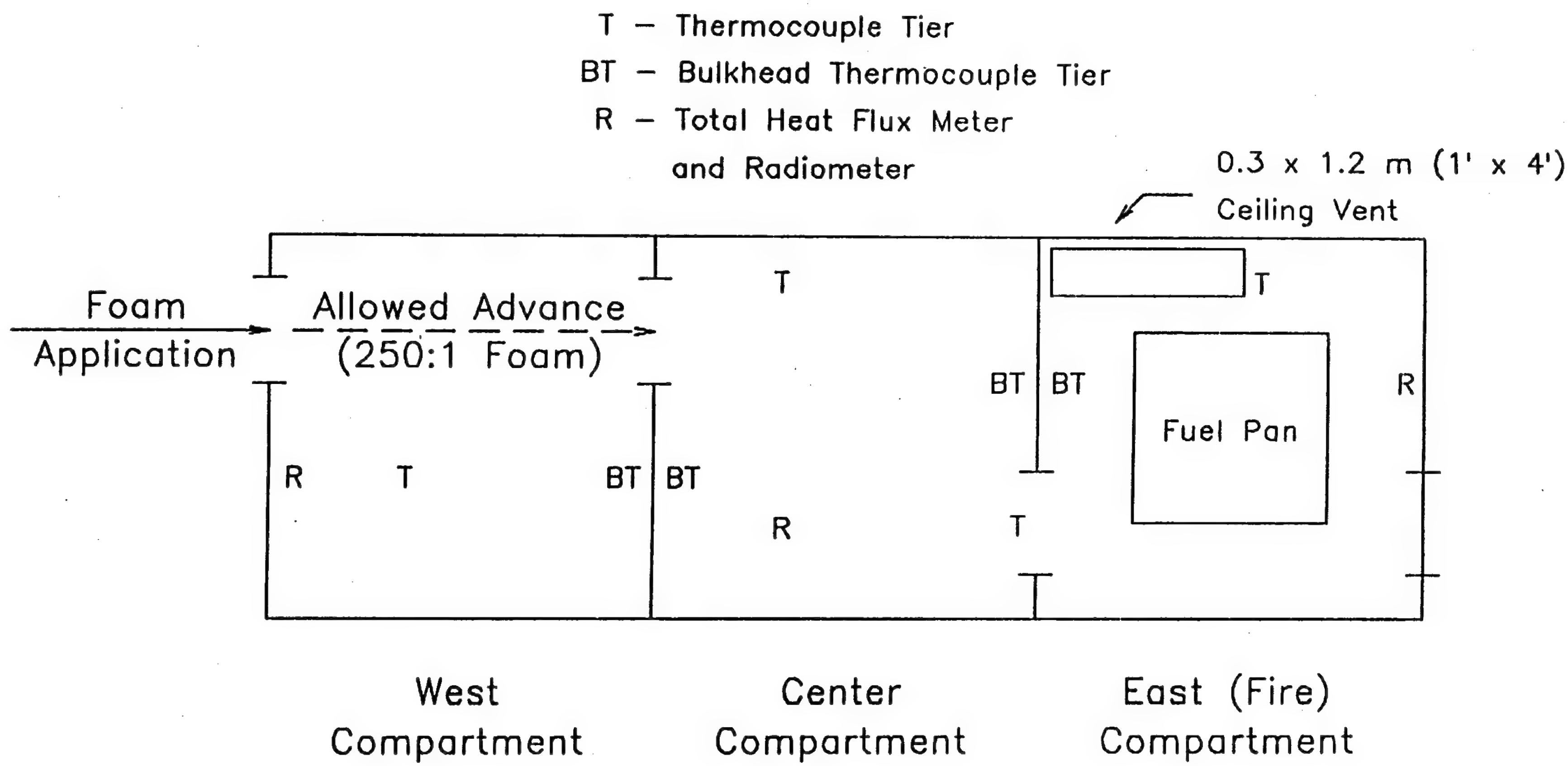

Fig. 6 – Setup for extinguishment series tests

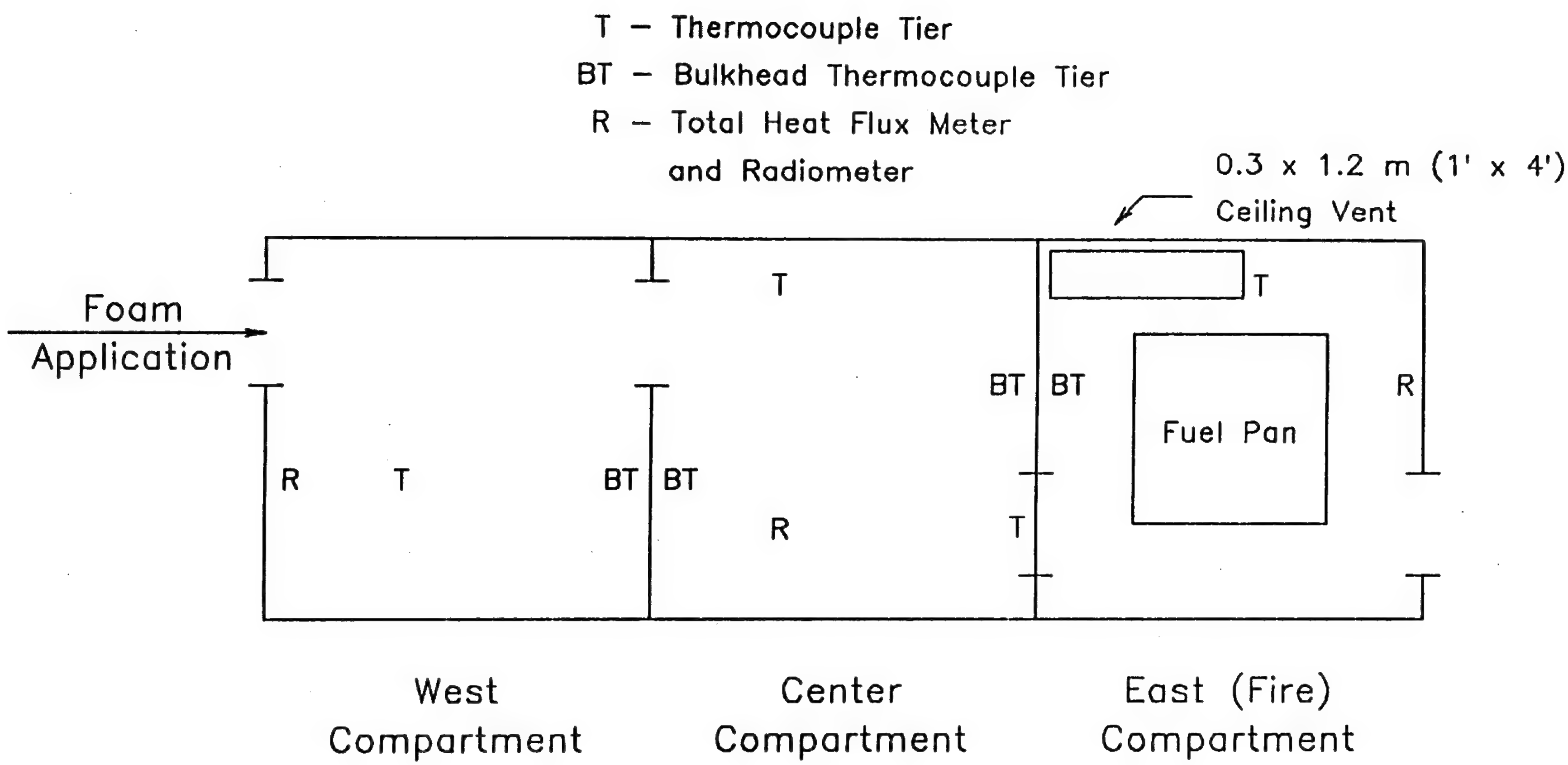

Fig. 7 – Setup for the cooling series tests

An additional vertical tier was used to determine the temperature profile at the entrance to the east compartment from the center compartment. It also had 8 thermocouples but with 15 cm (6 in.) intervals, starting 15 cm from the floor.

The surface temperature of the steel bulkheads separating the center compartment from the east compartment and the center from the west compartment was monitored with a vertical tier of type K glass braid thermocouples on both sides of the bulkhead. These thermocouples were welded to the bulkhead and were spaced on 61 cm (2 ft) intervals starting 15 cm (6 in) from the ceiling.

4.7.2 Heat Flux

Both the radiant heat flux and the total heat flux were monitored by a radiometer and total heat flux transducer in each of the three lower compartments. They were positioned 0.91 m (3 ft) above the floor, facing inward from the outside walls in the east and west compartments and facing straight up in the center compartment. An additional radiometer and heat flux transducer were located in the center compartment ceiling facing straight down. Both the heat flux transducers and the radiometers had ranges of 0 to 110 kW/m^2 (0 to 10 Btu/ft^2 s).

4.7.3 Video Recording

The application of the high expansion foam was video taped from the outside of the west compartment door.

4.8 Results

The results of these tests are divided into two sections by test series.

4.8.1 Extinguishment Series Results

An outline of the parameters (generator, concentrate, fire type, etc.) and results are given for extinguishment series of tests in Table 1. As can be seen, the success rate for the high expansion foam was encouraging, as 7 out of 9 test fires were extinguished.

The temperature profile in the east (fire) and center compartments and the measured heat fluxes in the east compartment for test 7 are given in Figs. 8, 9 and 10. The temperature profiles and measured heat fluxes for all the tests in this series are given in Appendix A. Note that high expansion foam is a thermal insulator, and therefore, the heat flux meters and radiometers will not read anything while submerged in the foam.

In the first test it was difficult to tell visually whether or not the fire was extinguished. However, the temperature profile in the east compartment and the measured heat fluxes for this test suggest that extinguishment may have occurred (see Appendix A).

Table 1. Extinguishment Series Tests

Test	Fire Type	Foam Generator	Concentrate	Vent Opening	Ext.	Duration of Foam Application	Fuel Shutoff Time	Comments
1	Class B pan fire	500:1	VEEFoam	Closed	?	1:00	12:00	
2	Class B pan fire	500:1	VEEFoam	0.37 m^2	Yes	1:35	19:00	16:00 Agent on
3	Class B pan fire	250:1	VEEFoam	0.37 m^2	Yes	2:30	14:00	
4	Class A wood crib	500:1	VEEFoam	0.37 m^2	Yes	1:15	--	
5	Class A wood crib	250:1	VEEFoam	0.37 m^2	Yes	2:30	--	
6	Class B vertical spray	500:1	Fire service	Closed	No	0:50	15:00	Fuel perculates through foam
7	Class B vertical spray	500:1	Fire service	0.37 m^2	Yes	1:00	12:00	
8*	Class B vertical spray	500:1	Fire service	0.37 m^2	Yes	1:00	12:00	
9*	Class B vertical spray	250:1	Fire service	0.37 m^2	Yes	2:30	14:00	Bad concentrate

* A pan was placed by the nozzle and a grating section was leaned onto the pan. It fell over when it got hot, before the application of foam, and had no effect on the test.

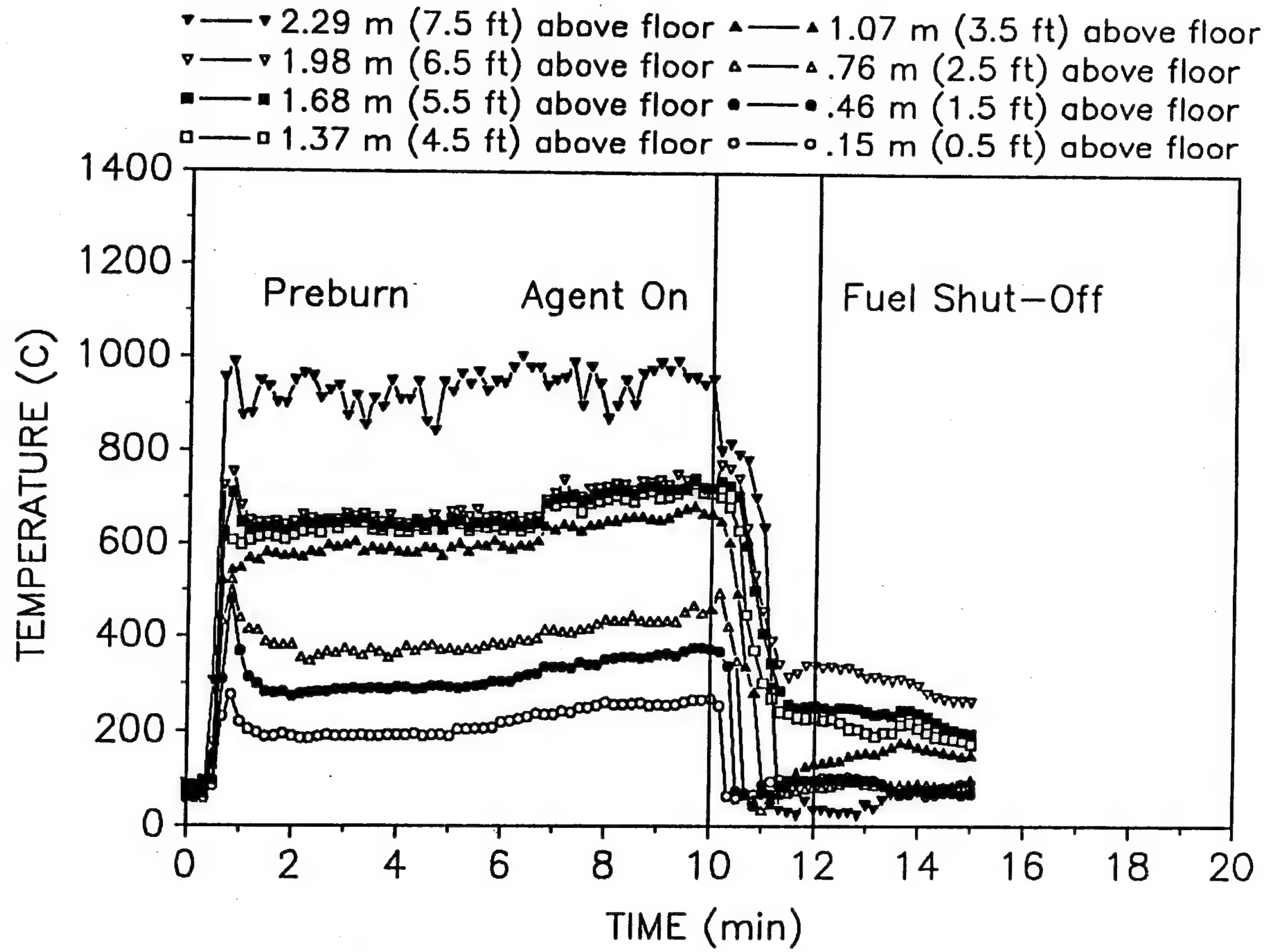

Fig. 8 – East (fire) compartment temperature during test 7

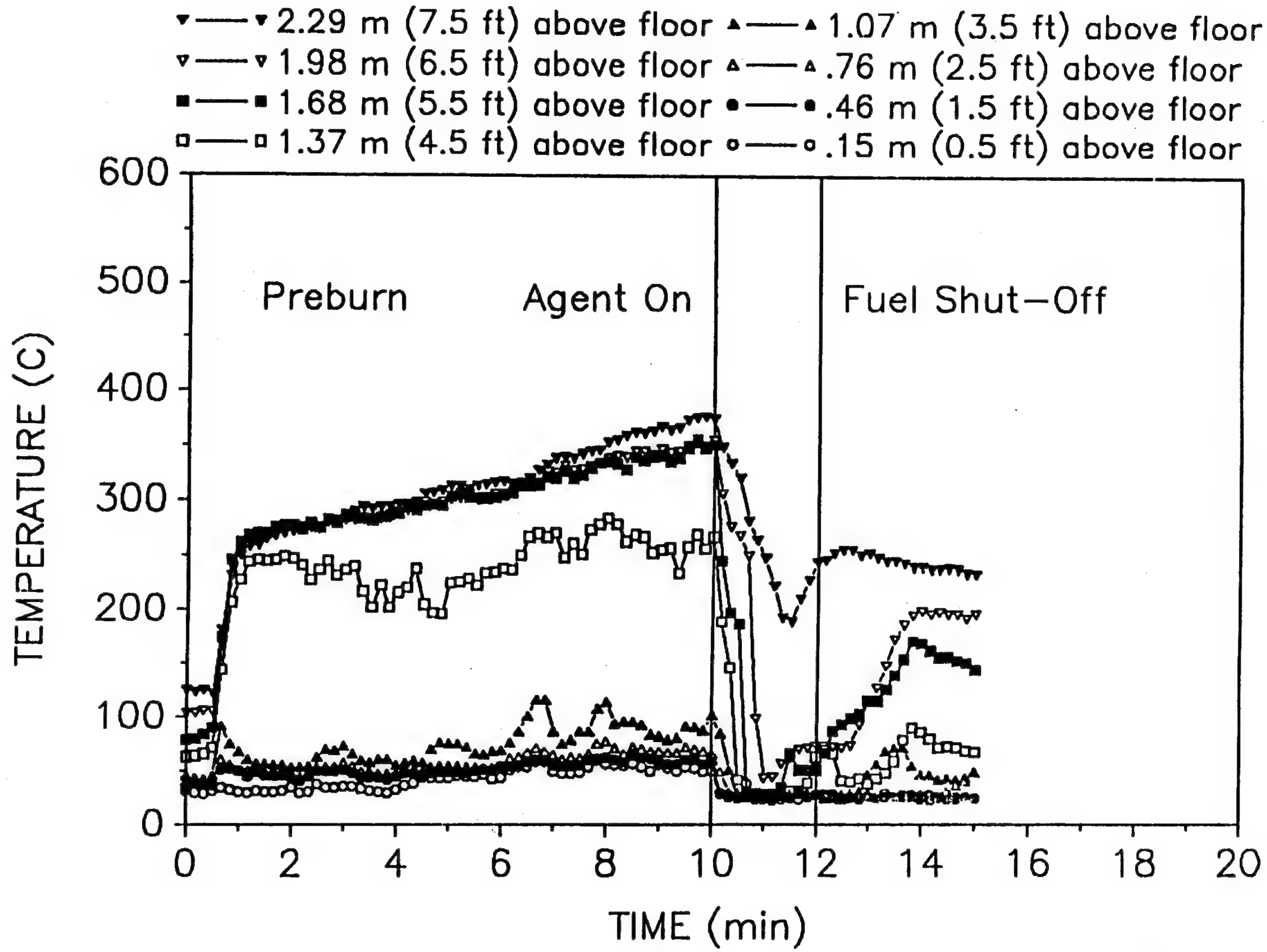

Fig. 9 — Center compartment temperature during test 7

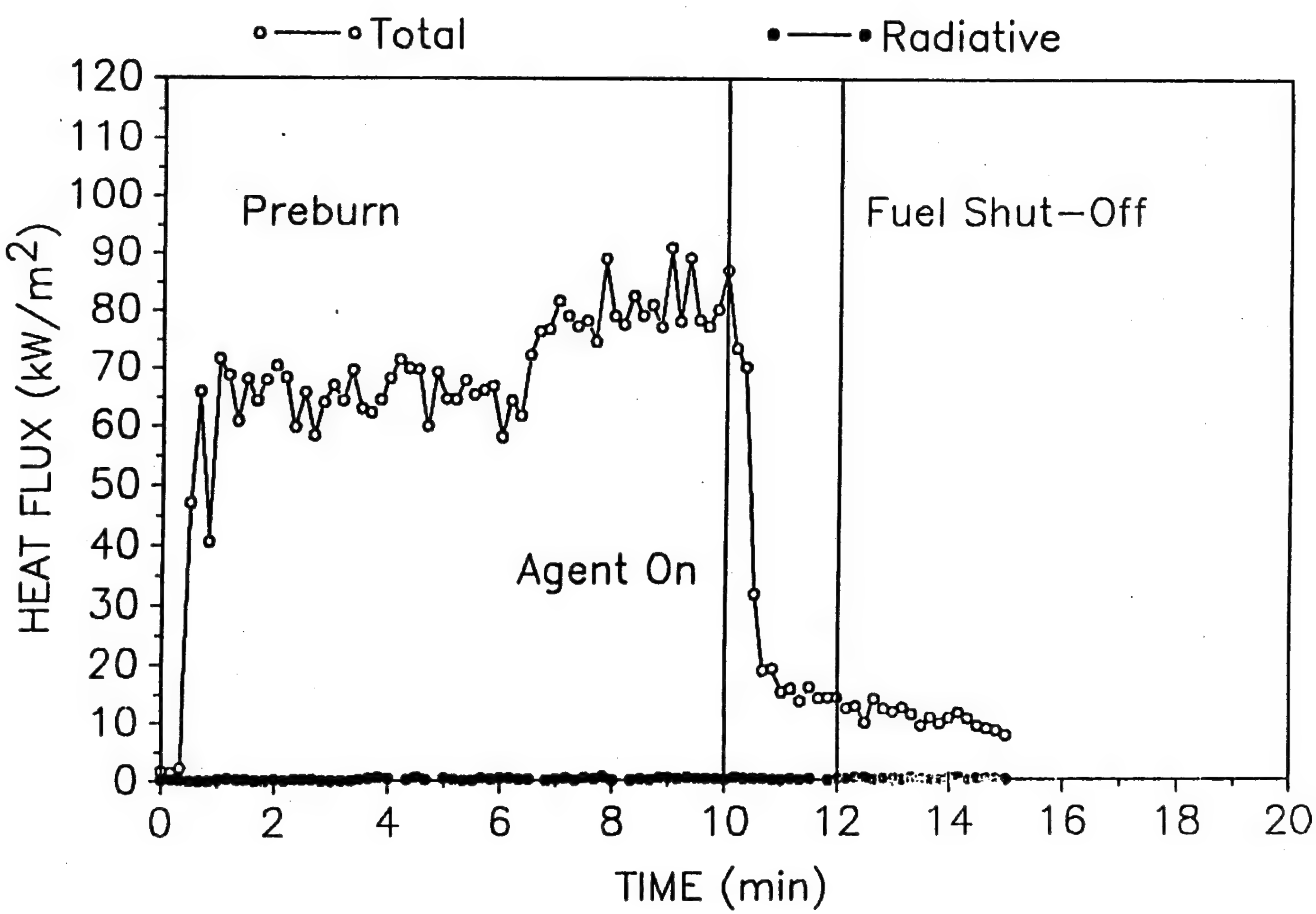

Fig. 10 — Heat flux in east (fire) compartment during test 7

In order to make an accurate determination of extinguishment, the ceiling vent in the east compartment was opened to a length of 0.3 m (1 ft) for an opening area of 0.37 m^2 (4 ft^2) in the remaining tests. This also reduced the temperature in the center and west compartments, increased the flow of air into the east compartment, and reduced the flow of smoke through the center and west compartments.

Due to a momentary failure of the gasoline motor-driven generator in the second test, the preburn period was inadvertently extended to 16 minutes.

In the tests with Class A fires (tests 4 and 5), the wood cribs remained in the fire compartment for an hour after the test. No re-ignition occurred in either test. In test 4, the door to the outside from the fire compartment was open during this period.

In the tests with Class B vertical spray fires, the fire was observed to have short duration puffs of fire after the application of the 500:1 expansion foam. In the first test, this was judged to be an ongoing event (i.e., not ending) and the fuel was turned off. In the second test, this puffing occurred a couple of times but then quit.

In test 9, the concentrate used was from a second fire service high expansion foam concentrate container and the quality of the foam was not similar to that made from the other concentrates. The foam did not build up in the compartments anywhere near as fast, but still extinguished the test fire. Upon examination after the test, the concentrate was observed to have a darker color. Test 9 was the only test in which this concentrate was used.

The fill time for the 500:1 expansion foam was approximately 1 minute and 2.5 minutes for the 250:1 expansion foam.

4.8.2 Cooling Series Results

The parameters used in this series of tests are shown in Table 2. The temperature profile in the center compartment and on both sides of the bulkhead separating the center and east compartments for test 11 are shown in Figs. 11 and 12. The temperature profiles for all the tests in this series are shown in Appendix B.

Table 2. Cooling Series Tests

Test	Fire Type	Foam Generator	Concentrate	Duration of Foam Application	Fuel Shutoff Time	Comments
10	Class B vertical spray	250:1	Fire service	2:30	12:30	
11	Class B vertical spray	500:1	Fire service	0:45	15:00	

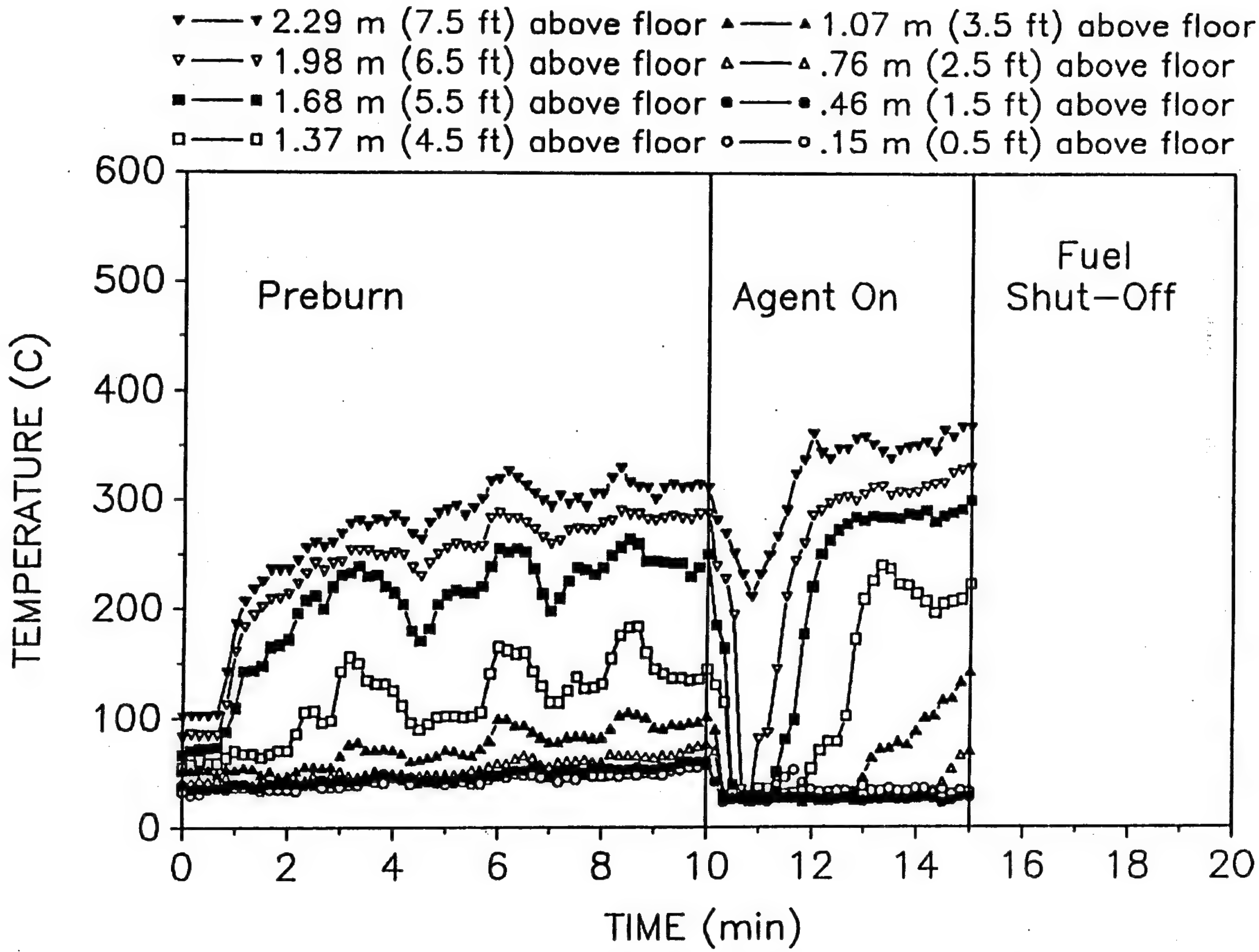

Fig. 11 — Center compartment temperature during test 11

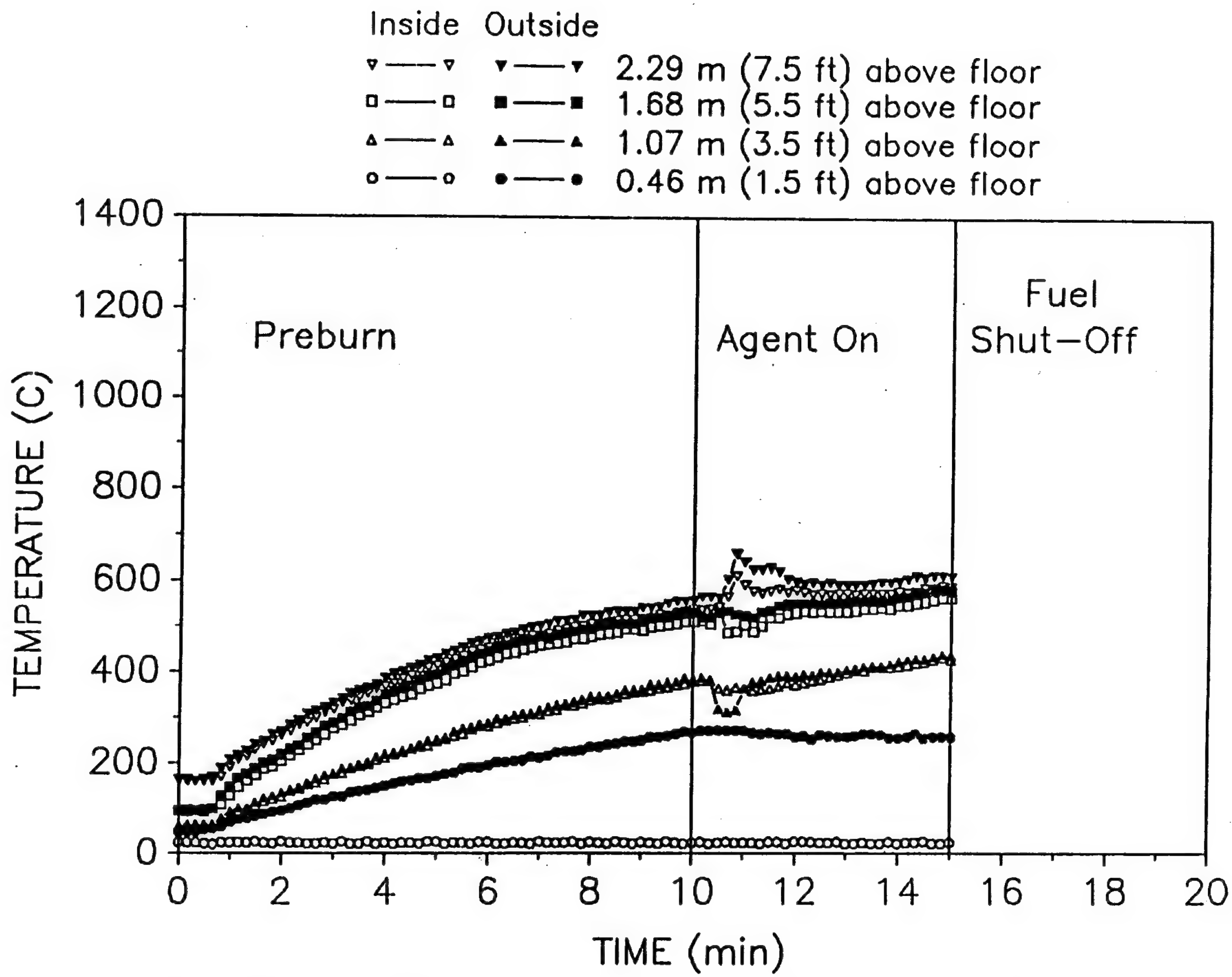

Fig. 12 – Bulkhead temperatures during test 11

The temperature in the center compartment was significantly reduced by the presence of either foam. As the foam degraded (broke down), the center compartment returned to the temperature it was at before the foam was applied. It took approximately 5 minutes for this to occur in test 11 (Fig. 11).

The temperature of the bulkhead separating the center and fire compartment was not significantly affected by the presence of either foam (see Appendix B).

These results indicate that the foam primarily acts as a thermal insulator.

5.0 CONCLUSIONS

These tests demonstrated that high expansion foam can be an effective fire suppression agent. It was able to extinguish intense Class B pan, Class B vertical spray, and Class A fires. The foam was shown to flow through two compartments with offset doorways (not in a straight line) to get to these fires.

These tests demonstrated that high expansion foam also has a cooling effect on a compartment that is flooded. This is due primarily to the foam acting as a thermal insulator. However, in order to take advantage of this effect, the compartment would have to be periodically reflooded with foam.

The application of high expansion foam to shipboard fire protection has significant promise. The ability to effectively fight a fire from a remote location and the reduced water consumption of the foam and the consequent reduction in water damage are definite advantages. However, loss of access to the space, and removal of the foam (cleanup of the space) remain as potential obstacles.

6.0 ADDITIONAL INVESTIGATION

Additional investigation is needed in order to evaluate the application of high expansion foam in shipboard spaces. This should include investigation into the effects of filling time (application rate), the effectiveness of the foam on other types of fires and configurations, the use of foams made from salt water, the removal of foam and cleanup of spaces after extinguishment, the effects of foam parameters and properties, and the effects of various ventilation system parameters, particularly for venting air displaced by the foam.

6.1 Filing Time

In these preliminary investigations, the 500:1 expansion foam generator was able to flood all three compartments in approximately one minute. A longer flooding time would significantly reduce the number and/or size of the generators required in the larger shipboard spaces (machinery rooms, store rooms, etc.), as well as reducing the cost of protecting these spaces. The National Fire Protection Association in their standard on high expansion foam systems gives a flooding time requirement of 2 to 5 minutes depending on the type of hazard protected [3]. Therefore, an investigation is needed into the effects of longer filling times.

6.2 Other Fire Types and Configurations

Additional investigation is needed into the effectiveness of high expansion foam on other fire types and geometrical configurations. These include electrical and electrical cable fires, fires high in the space, effects of introducing the foam from high in the space, etc.

6.3 Salt Water Foams

In shipboard application, high expansion foam would likely be generated from salt water, due to the limited quantities of available fresh water. While concentrates are commercially available for use with salt water, an investigation should be conducted on their effectiveness. Side effects of the use of salt water should also be investigated, including electrical shock hazards, and increased equipment damage (corrosion) following immersion.

6.4 Foam Destruction/Cleanup

In view of the inaccessibility of a compartment flooded with high expansion foam, an investigation should be conducted into methods of quickly removing the foam and regaining access to the space. The methods to investigate include: existing ventilation system, portable fans, etc.

6.5 Foam Parameters and Properties

An investigation should be conducted into the effects of the foam making parameters and the physical properties of the resulting foams. This investigation would focus on finding an optimum expansion ratio and foam performance requirements (drainage rate, etc.) for broad shipboard use. Also, the ability to generate foam in a full scale shipboard machinery space using smokey air should be demonstrated.

6.6 Ventilation System Effects

The effects of various ventilation system parameters (configuration, size, etc.) need to be investigated. These effects are greatest when the ventilation system cannot provide the necessary fresh air required to generate the foam.

7. REFERENCES

1. Robert E. Havener, "Application of High-Expansion Foam to Fight Underground Mine Fires," Coal Age, Vol. 80, No. 2, Feb. 1975.

2. Allan S. Hodgson, "High Expansion Foam Fire Protection Systems," Technical Note N-1016, Naval Civil Engineering Laboratory, Port Hueneme, CA, Feb. 1969.

3. National Fire Protection Association, "Standard for Medium and High Expansion Foam Systems," NFPA No. 11A, Batterymarch Park, Quincy, MA, 1988.

4. J.R. Welker, W.E. Martinsen, and D.W. Johnson, "Effectiveness of Fire Control Agents for Hexane Fires," Fire technology, Vol. 22, No. 4, Nov. 1986.

5. R.C. Richards, "High Expansion Foam Extinguishment of Machinery Space Fires," Report No. CG-D-83-76, United States Coast Guard, Mobile, AL, 1975.

6. M.J. Miller and E.W.J. Troup, "An Evaluation of High-Expansion Foam Systems for the Protection of Naval Shore Facilities," NCEL Report No. CR 69.004, Naval Civil Engineering Laboratory, Port Hueneme, CA, Oct. 1968.

7. D.H. Kay, "Design, Test, and Evaluation of Total Coverage Fixed Fire Extinguishing Systems for Machinery Spaces," NAVSEA 0993-LP-030-5010, Naval Ship Engineering Center, Hyattsville, MD, Feb. 1973.

8. W.B. Jamison, "Stability - The Key to Effective High Expansion Foam," Presented to the 73rd Annual Meeting of the National Fire Protection Association, New York, NY, May 1969.

9. MSA Research Corporation, "Information Package on Fire Protection Systems and Components," Evans City, PA, June 1988.

10. G.S. Holmstedt and H. Persson, "High Expansion Foam - Ability to resist Heat Flux," Technical Report No. SP-RAPP 1985:27, Statens Provningsanstalt, Sweden, 1985.

11. E.W. Spencer, "The Effect of High Expansion Fire Extinguishing Foam on Operation Electronic Equipment," ASSE Journal, Sept. 1964.

12. "Survival in High Expansion Foam," Fire Engineering, July 1968.

13. I. Wilder, "High Expansion Foam for Shipboard Fire Fighting," Fire Technology, Vol. 5, No. 1, Feb. 1969.

14. "Final Report of LHA Decontamination Operating Concept in a Sustained CBR and Conventional Weapon Hit Environment, and Recommendations for Personnel and Equipment for CBR and Fire Byproducts Decontamination," Contract N00024-84-C-7121, Autonetics Marine Systems Division, Rockwell International Corporation, Arlington, VA, Feb. 1986.

15. MSA Research Corporation, "Material Safety Data Sheet -VEEFoam Concentrate," Evans City, PA, 1988.

16. Chubb National Foam, Inc., "Material Safety Data Sheet -High Expansion," Lionville, PA, 1989.

17. N.J. Alvares and A.E. Lipska, "The Effect of Smoke on the Production and Stability of High-Expansion Foam," Presented at the 1971 Spring Meeting of the Western States Section of the Combustion Institute, Denver, CO, 1971.

18. R.S. Alger and N.J. Alvares, "Improved Fire Extinguishing System Development for the ULMS Submarine, Generation of High Expansion Foam with Contaminated Air," NOLTR 73-67, Naval Ordnance Laboratory, Silver Spring, MD, March 1973.

19. Underwriters Laboratories Inc., "Standard for Rating and Fire Testing of Fire Extinguishers," ANSI/UL No. 711, Northbrook, IL, 1979.

APPENDIX A

Extinguishment Series Tests

The temperature profiles in the east (fire) and center compartment and the measure heat fluxes in the east compartment are given for each test in the extinguishment series in Figures 13 through 39.

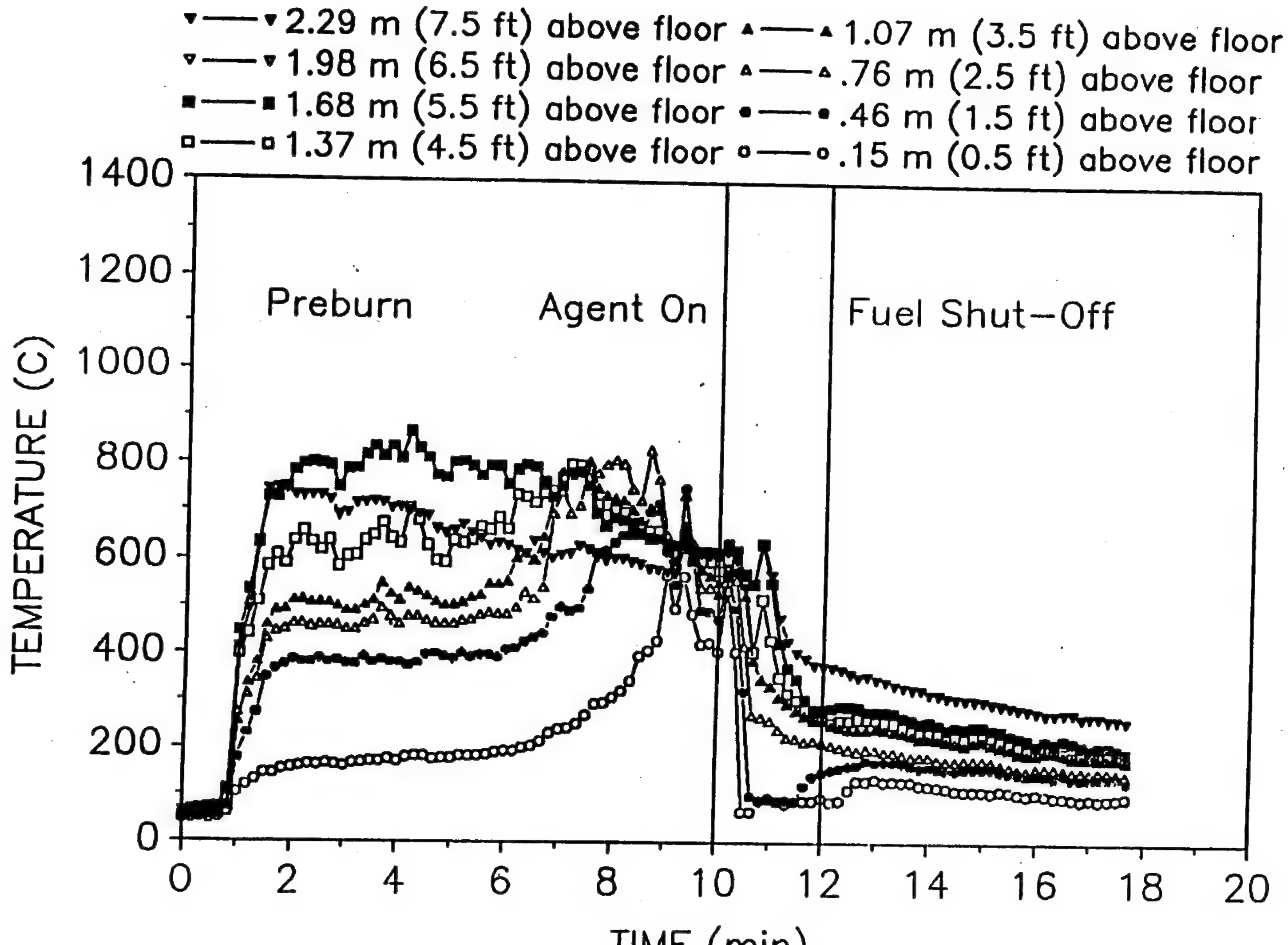

Fig. 13 — East (fire) compartment temperature during test 1

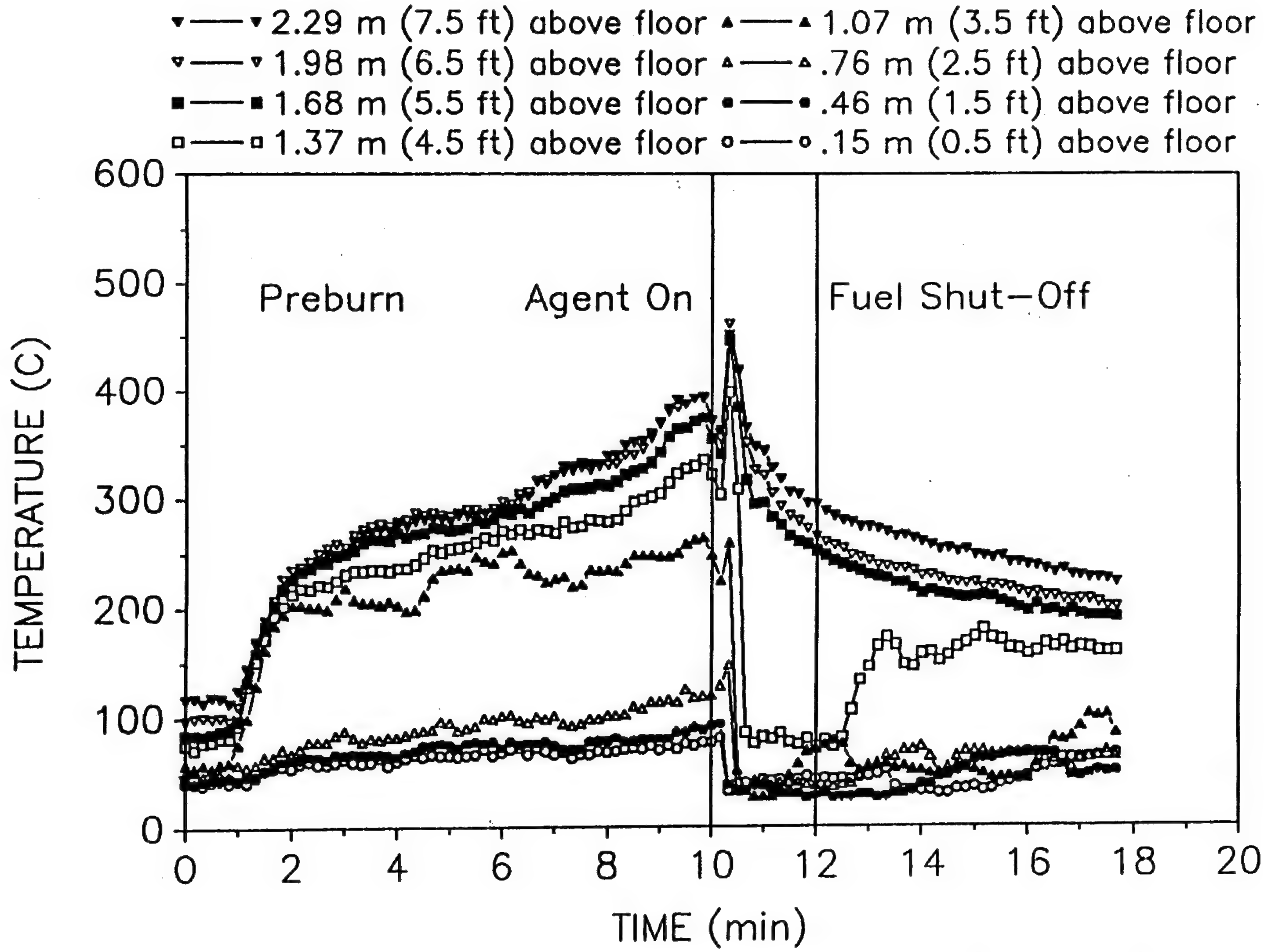

Fig. 14— Center compartment temperature during test 1

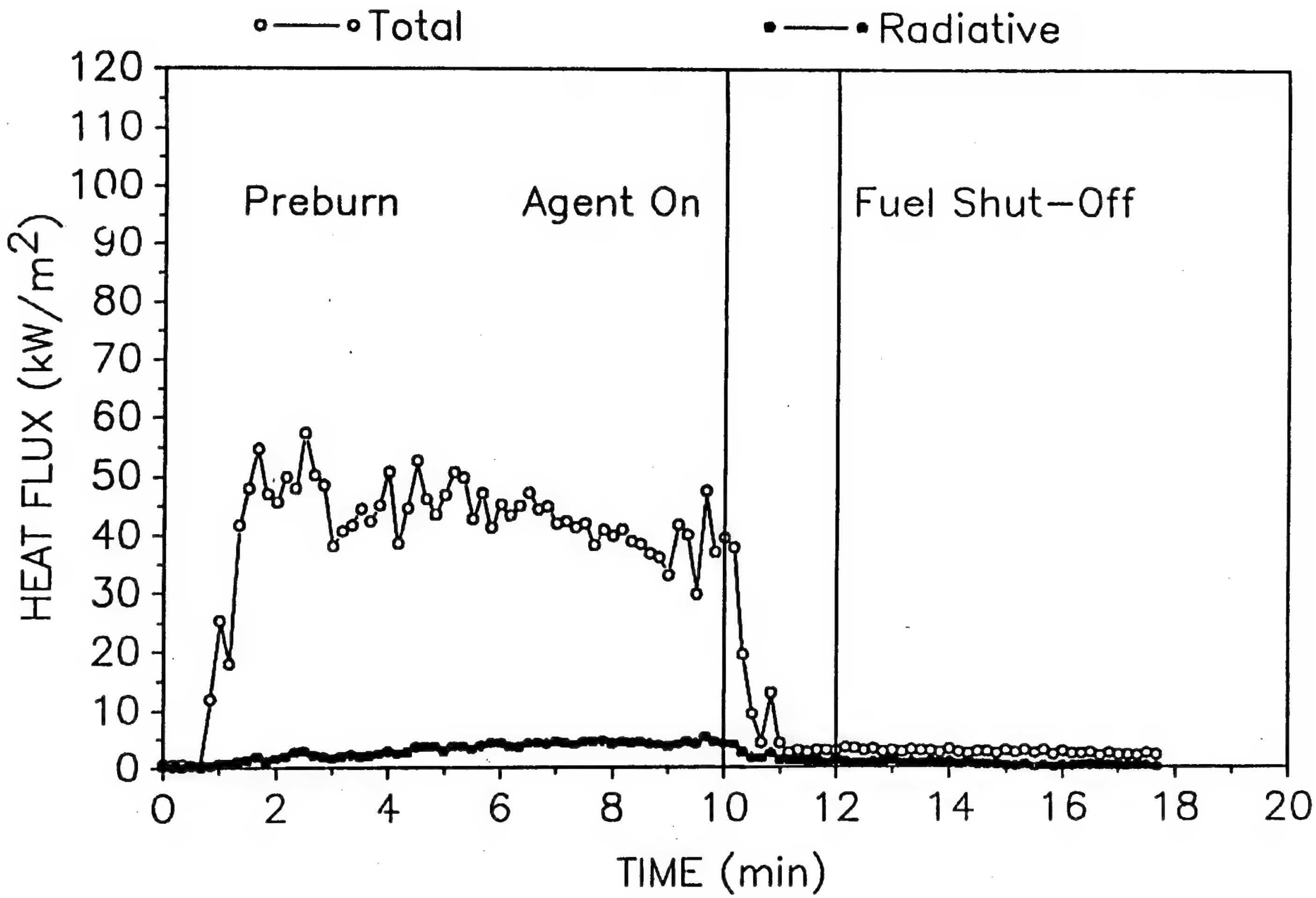

Fig. 15 – Heat flux in east (fire) compartment during test 1

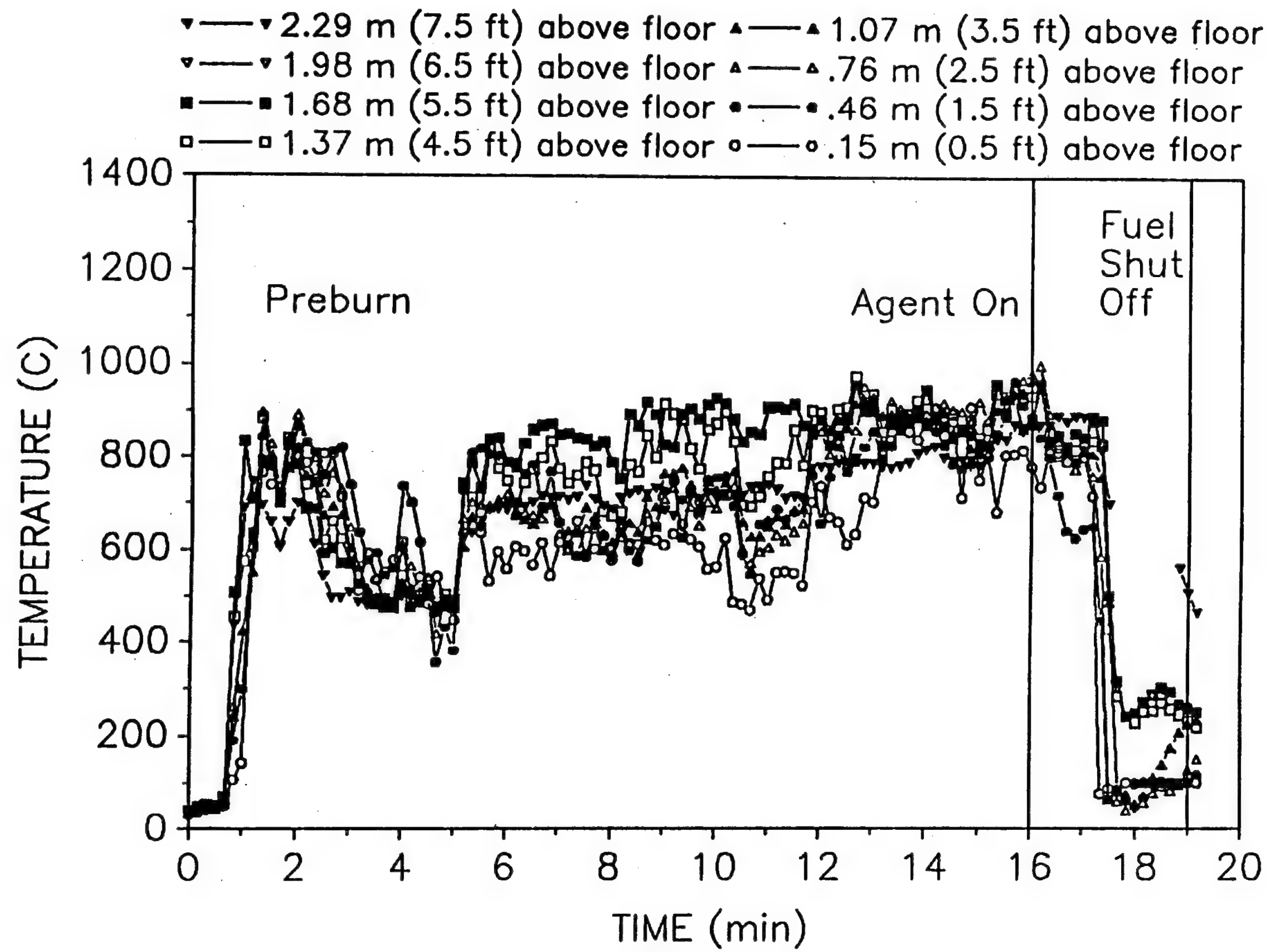

Fig. 16 – East (fire) compartment temperature during test 2

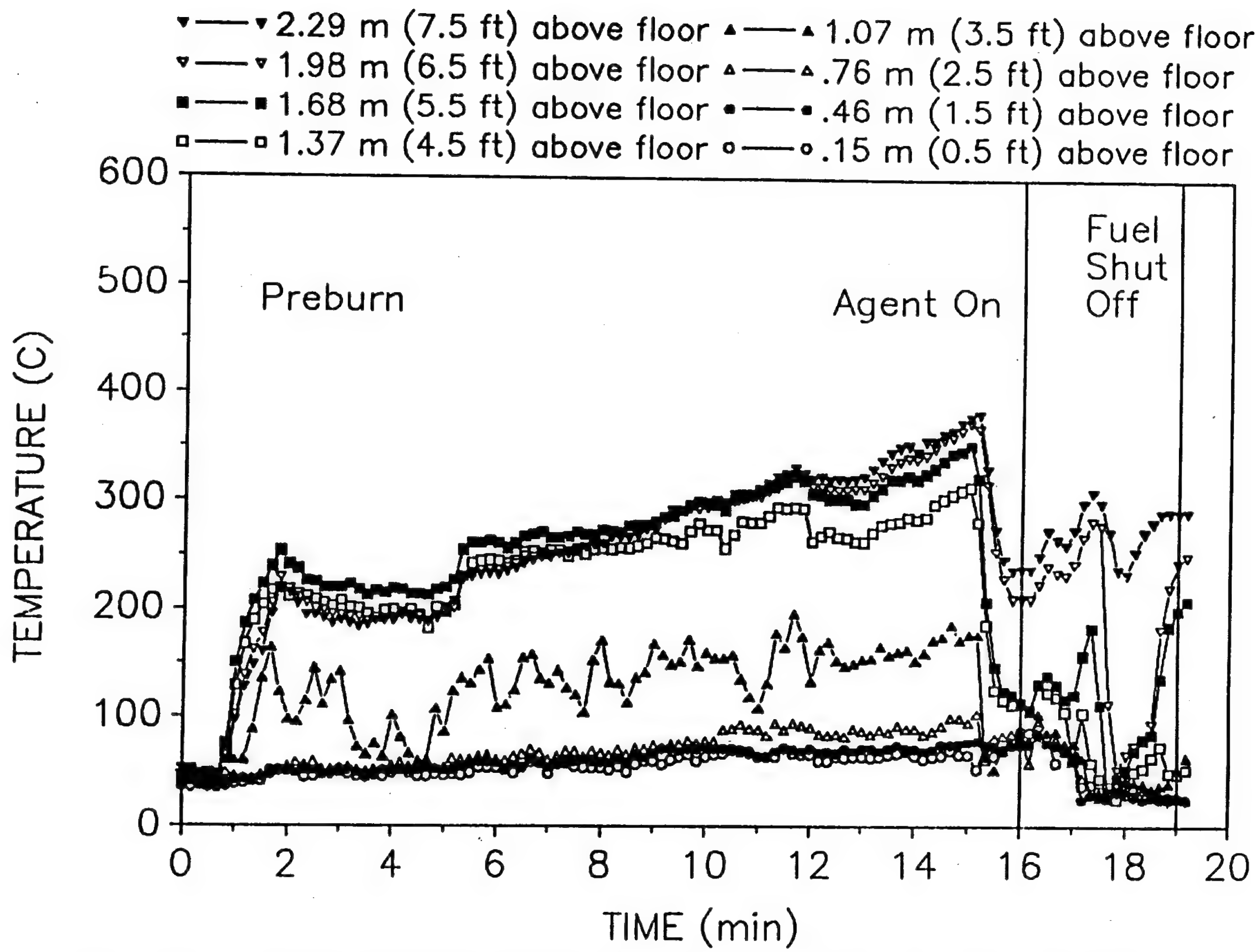

Fig. 17 — Center compartment temperature during test 2

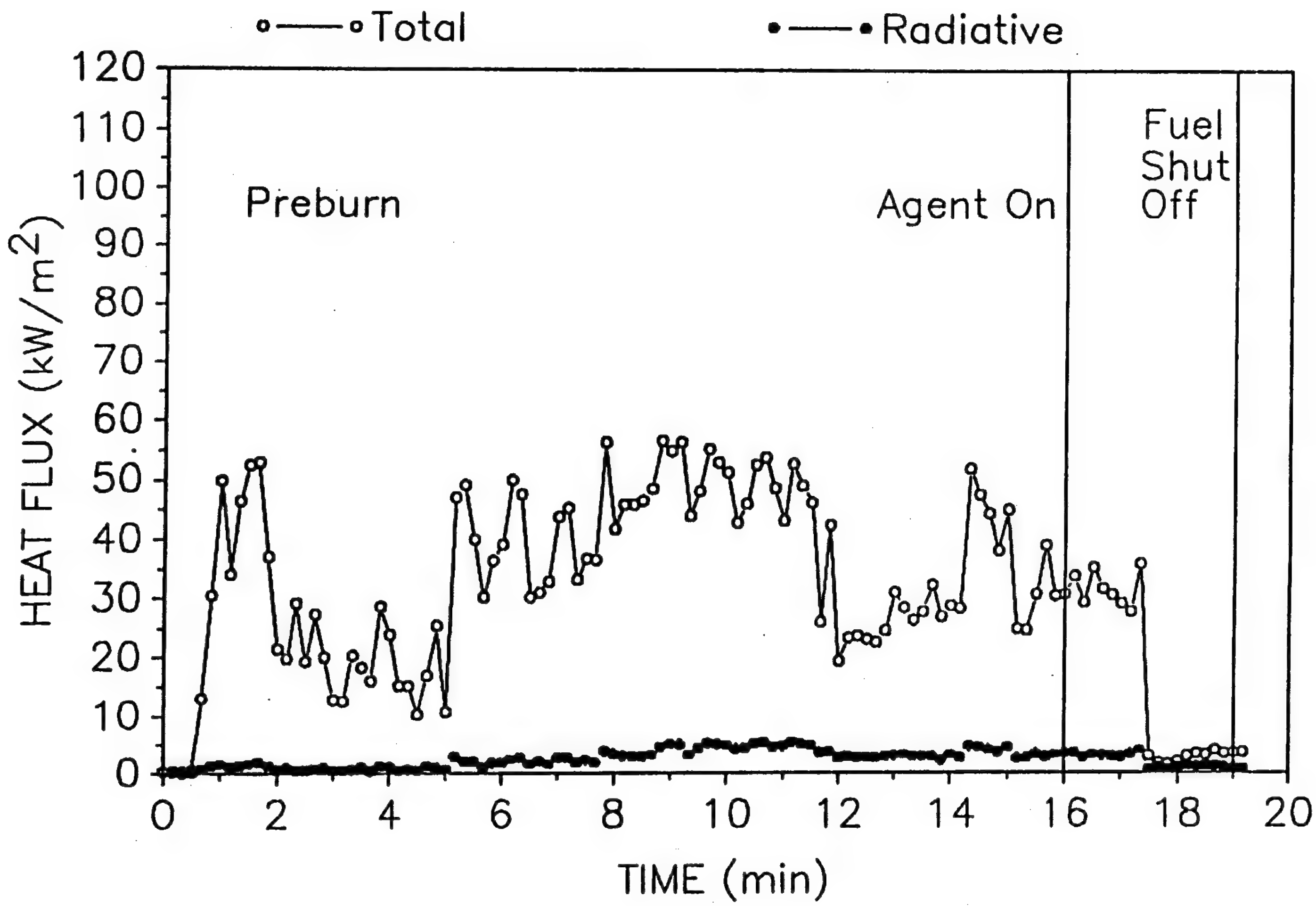

Fig. 18 — Heat flux in east (fire) compartment during test 2

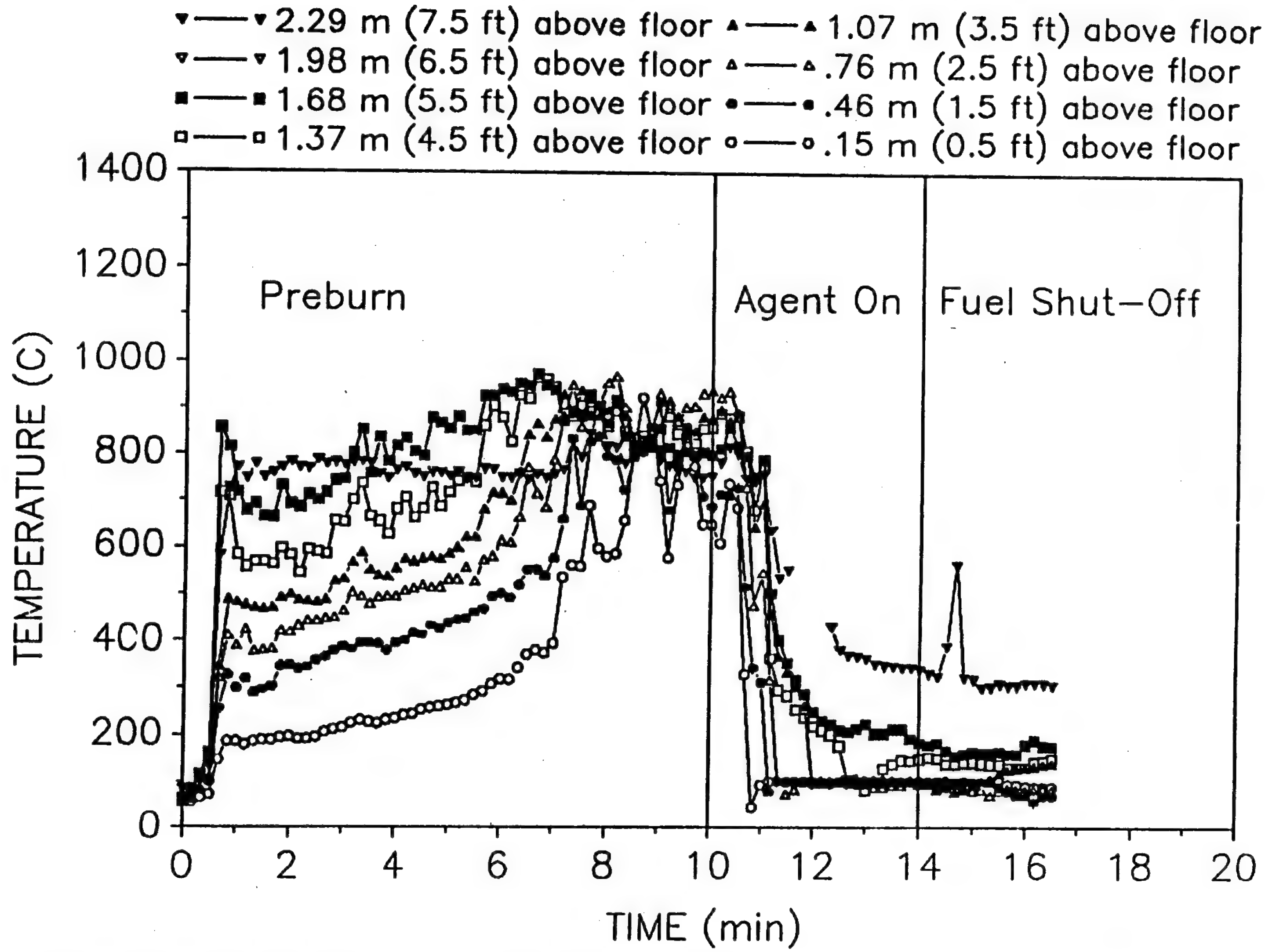

Fig. 19 — East (fire) compartment temperature during test 3

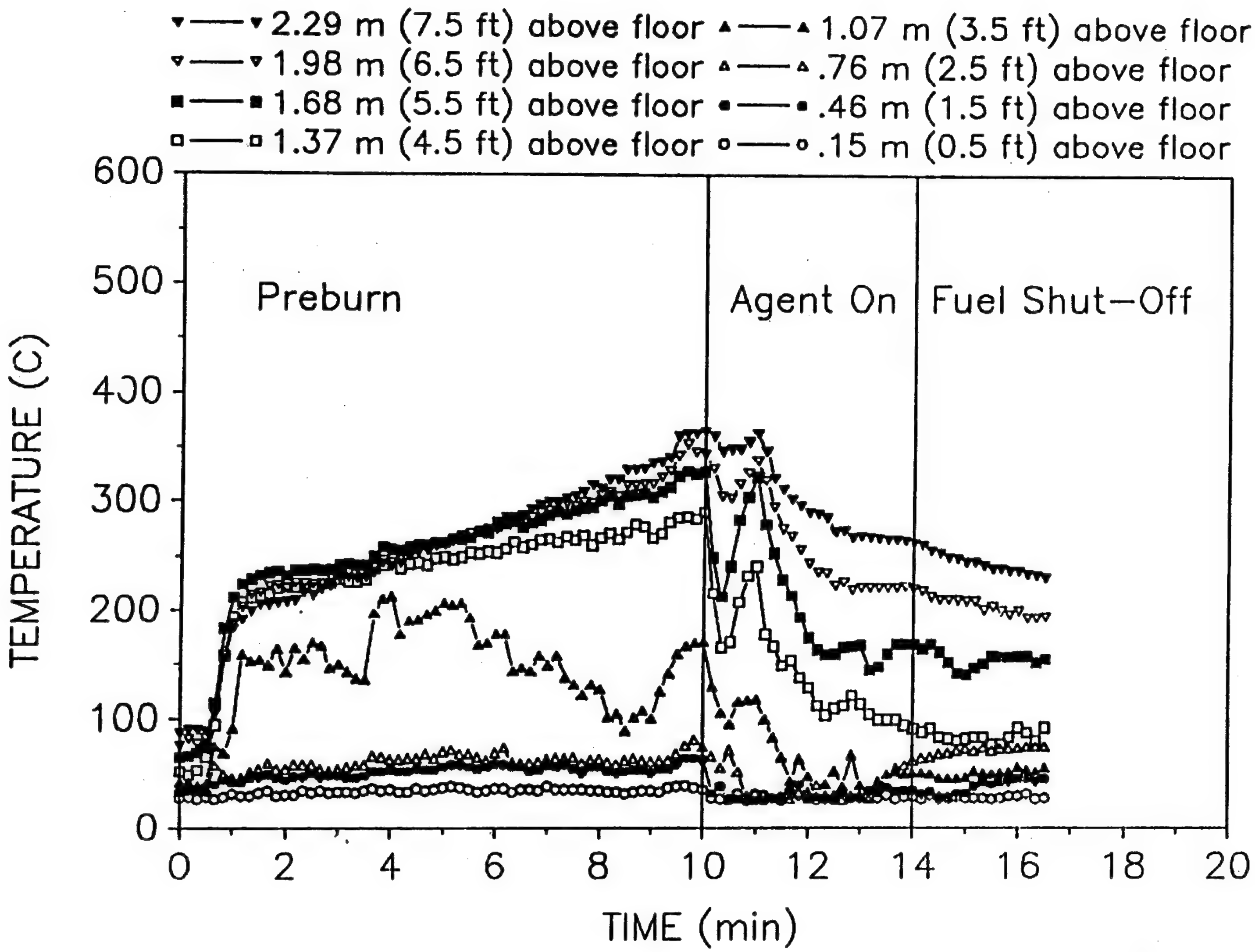

Fig. 20 — Center compartment temperature during test 3

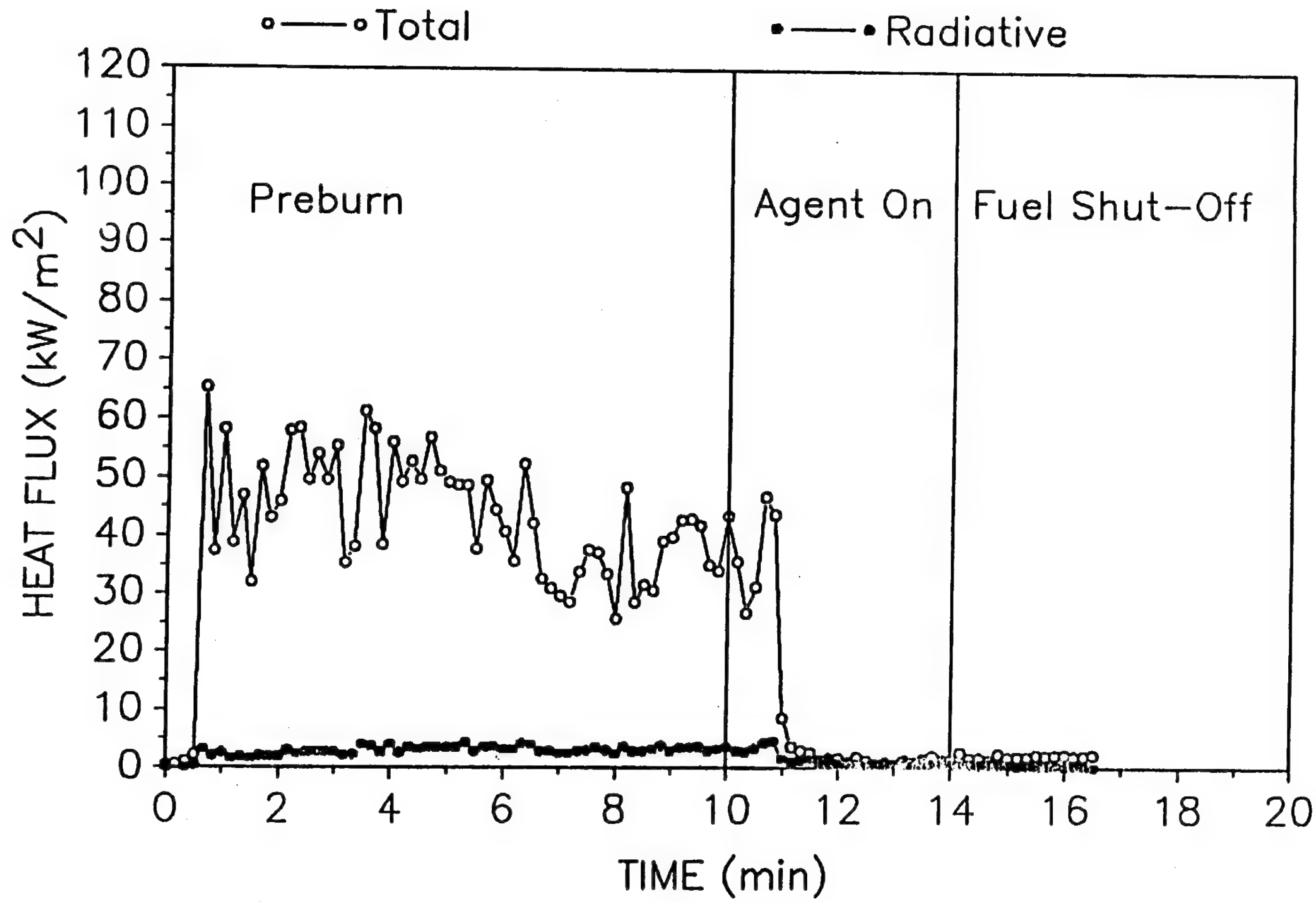

Fig. 21 — Heat flux in east (fire) compartment during test 3

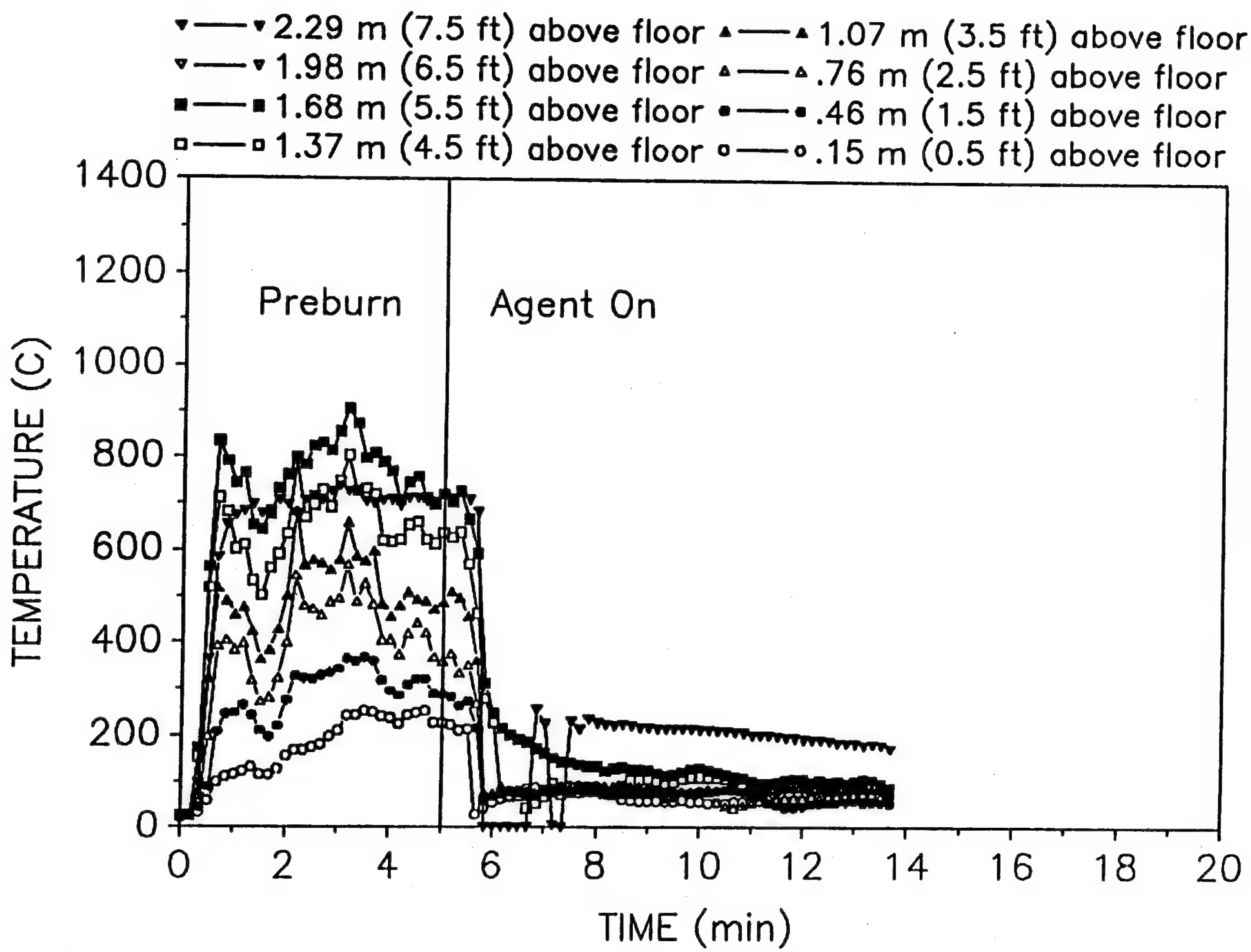

Fig. 22 — East (fire) compartment temperature during test 4

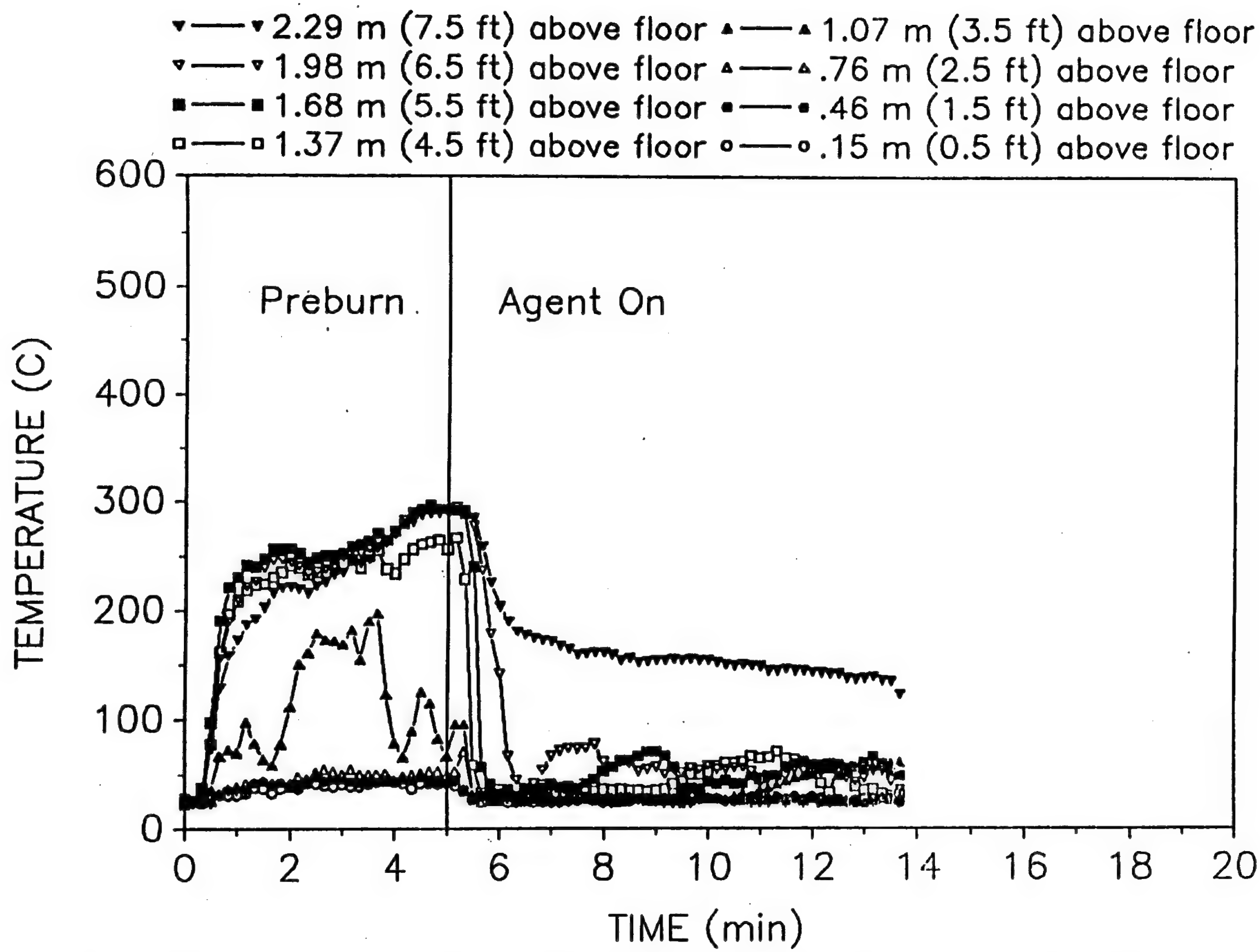

Fig. 23 — Center compartment temperature during test 4

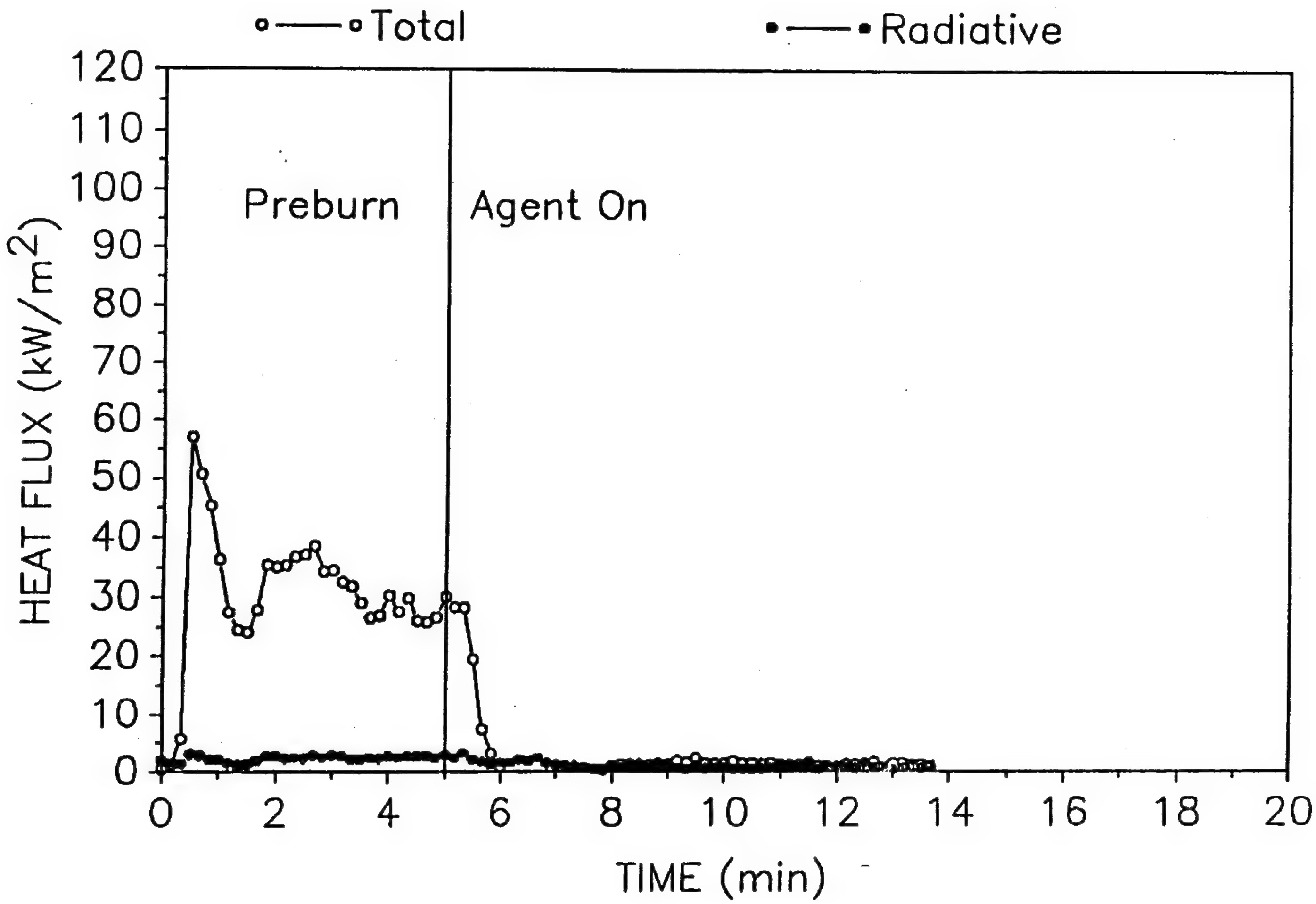

Fig. 24 – Heat flux in east (fire) compartment during test 4

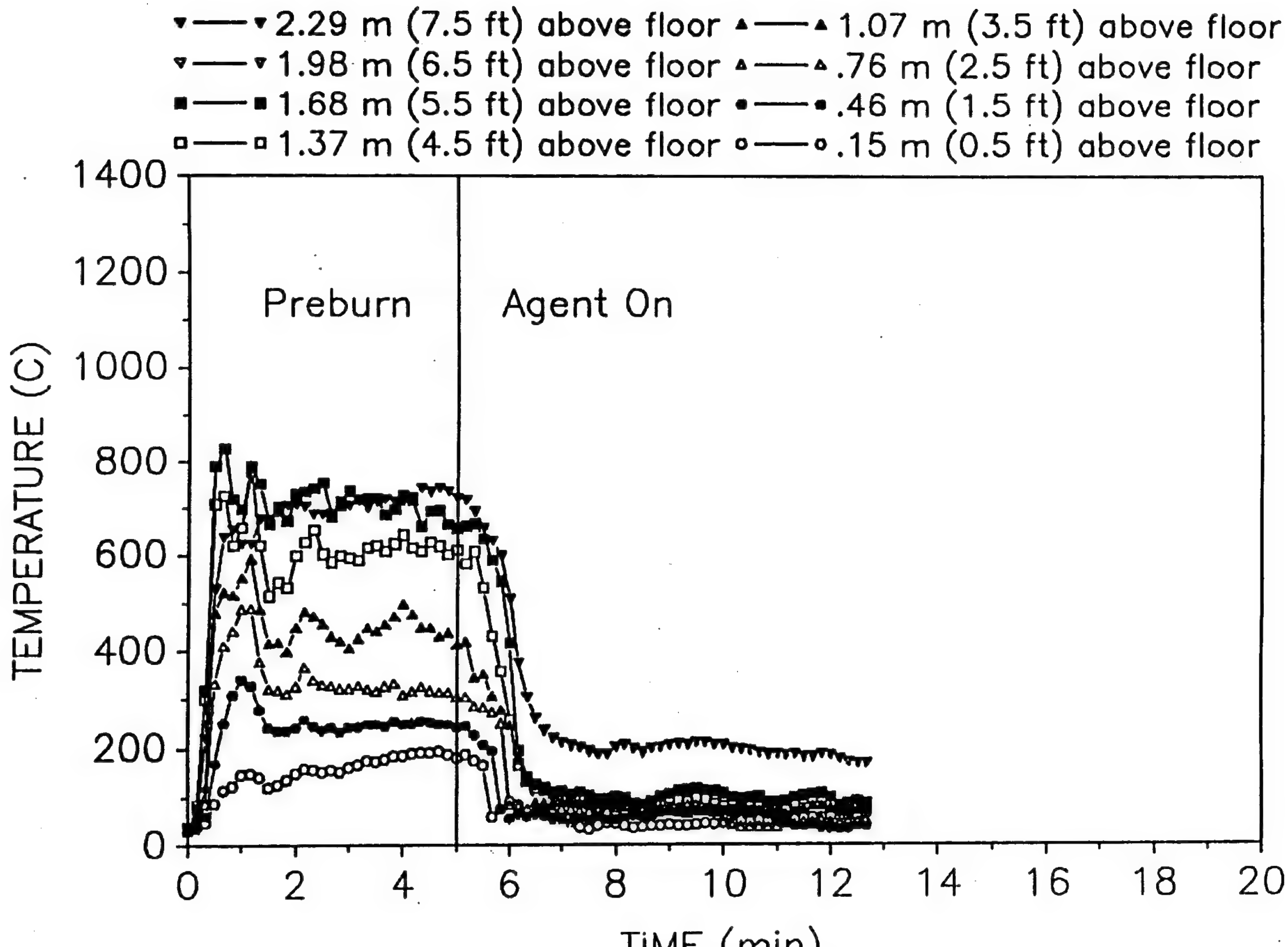

Fig. 25 – East (fire) compartment temperature during test 5

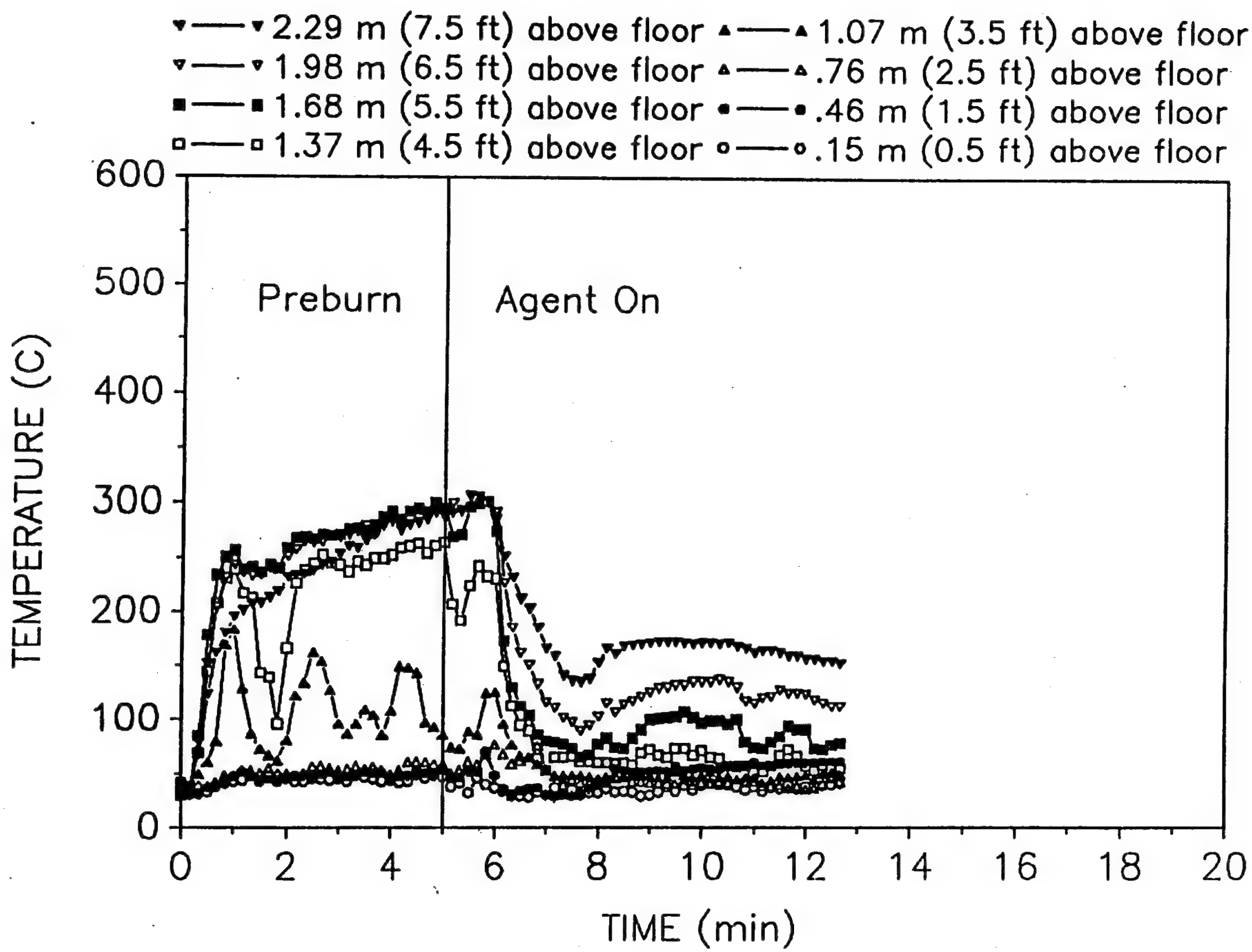

Fig. 26 — Center compartment temperature during test 5

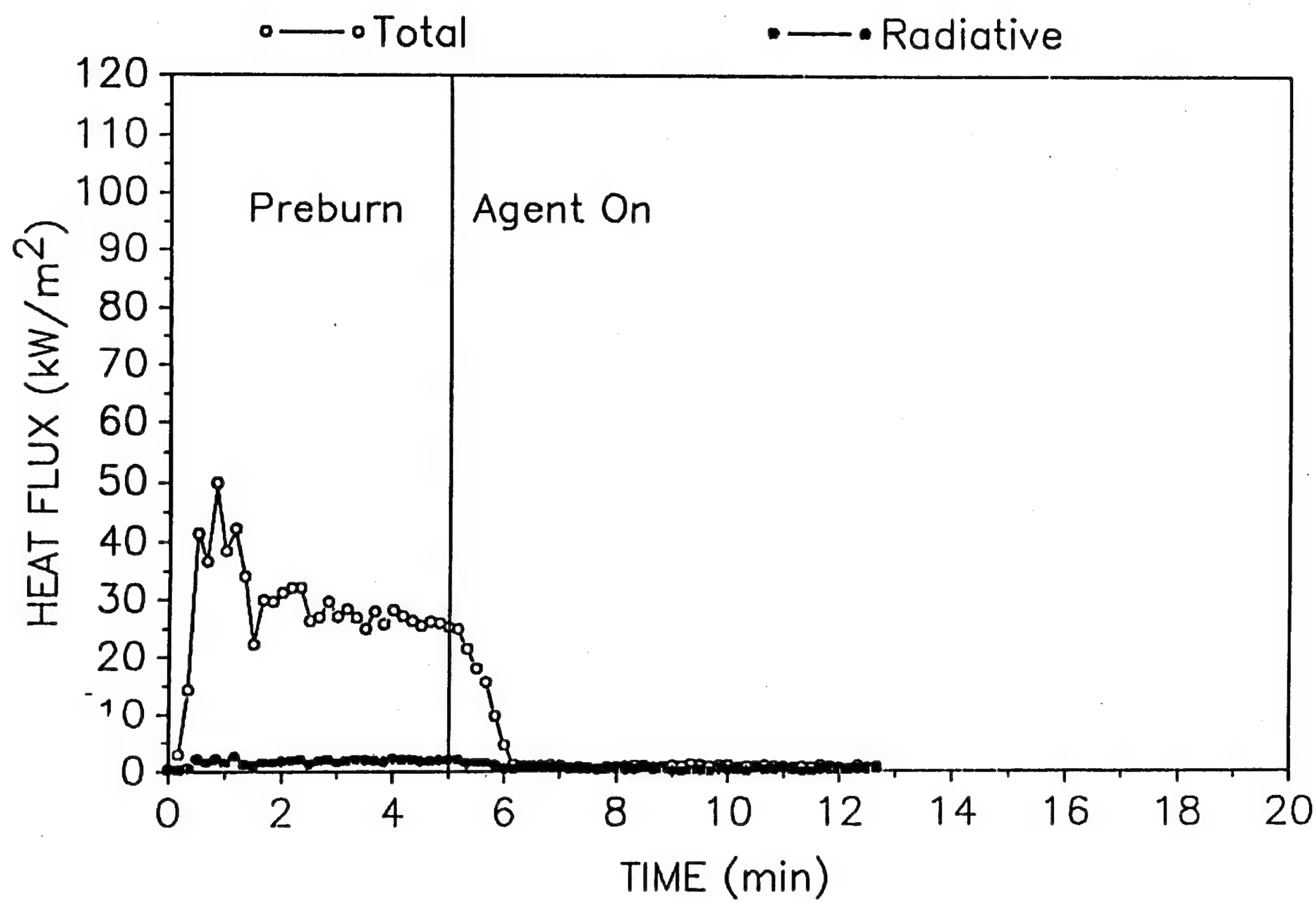

Fig. 27 – Heat flux in east (fire) compartment during test 5

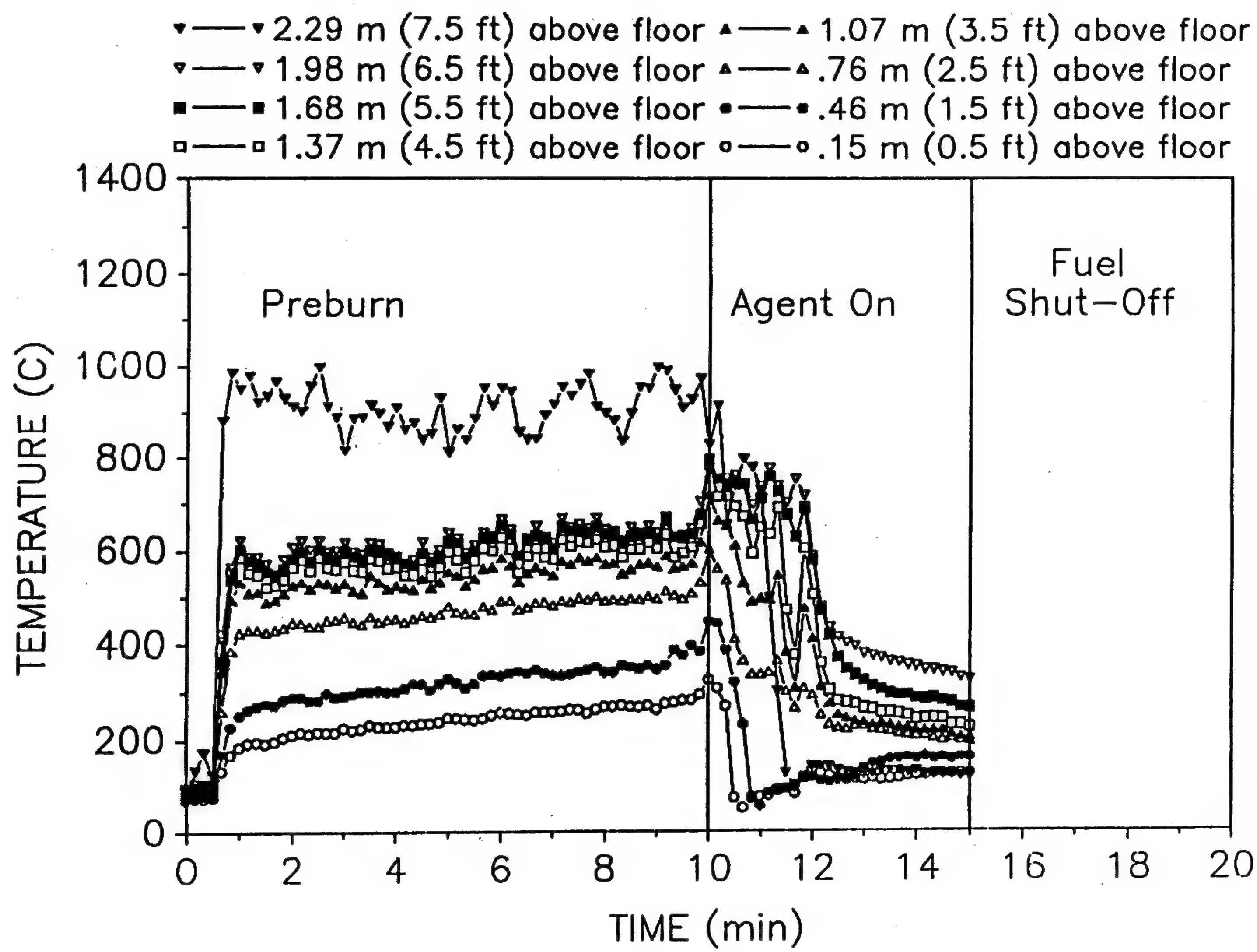

Fig. 28 — East (fire) compartment temperature during test 6

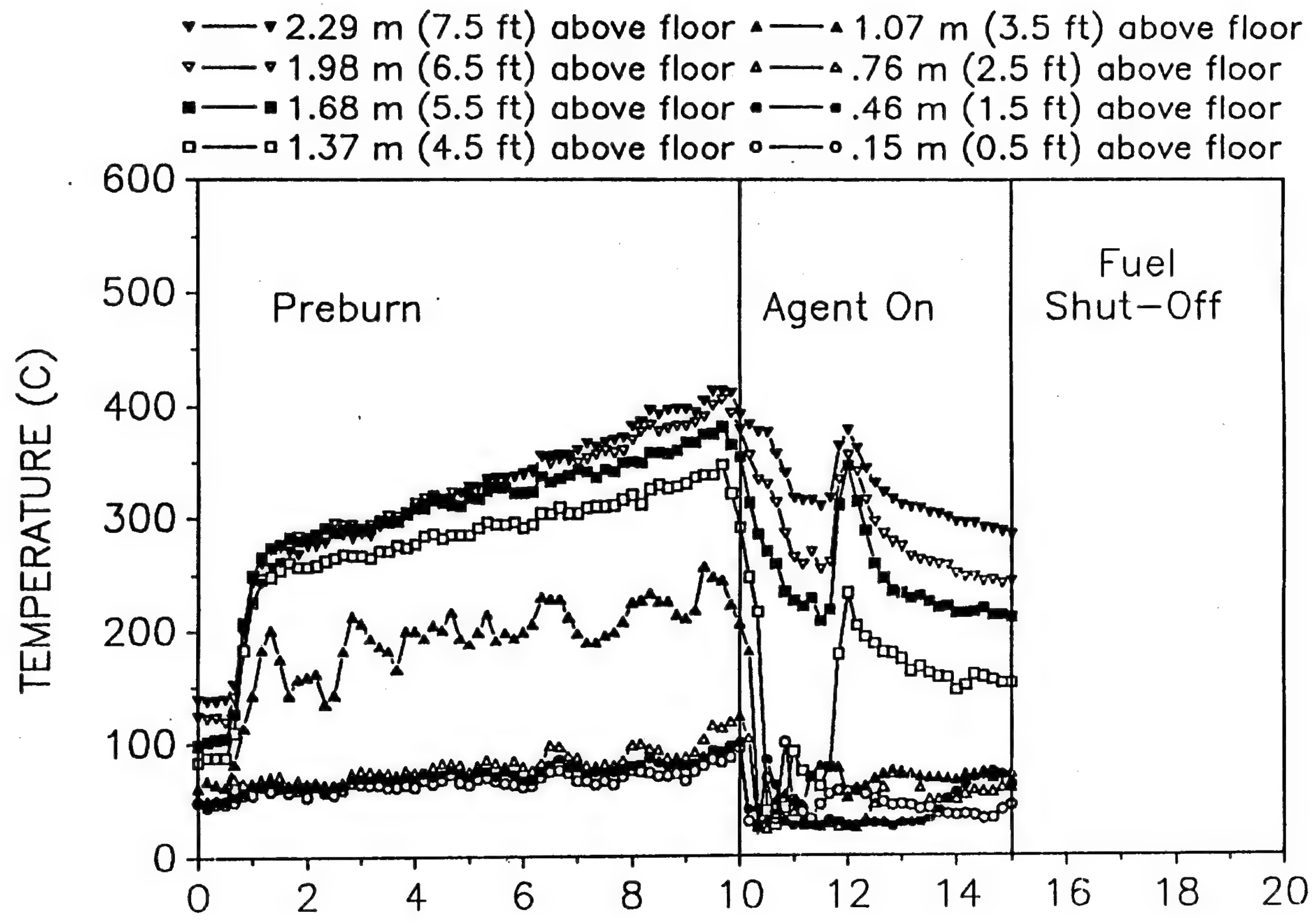

Fig. 29 – Center compartment temperature during test 6

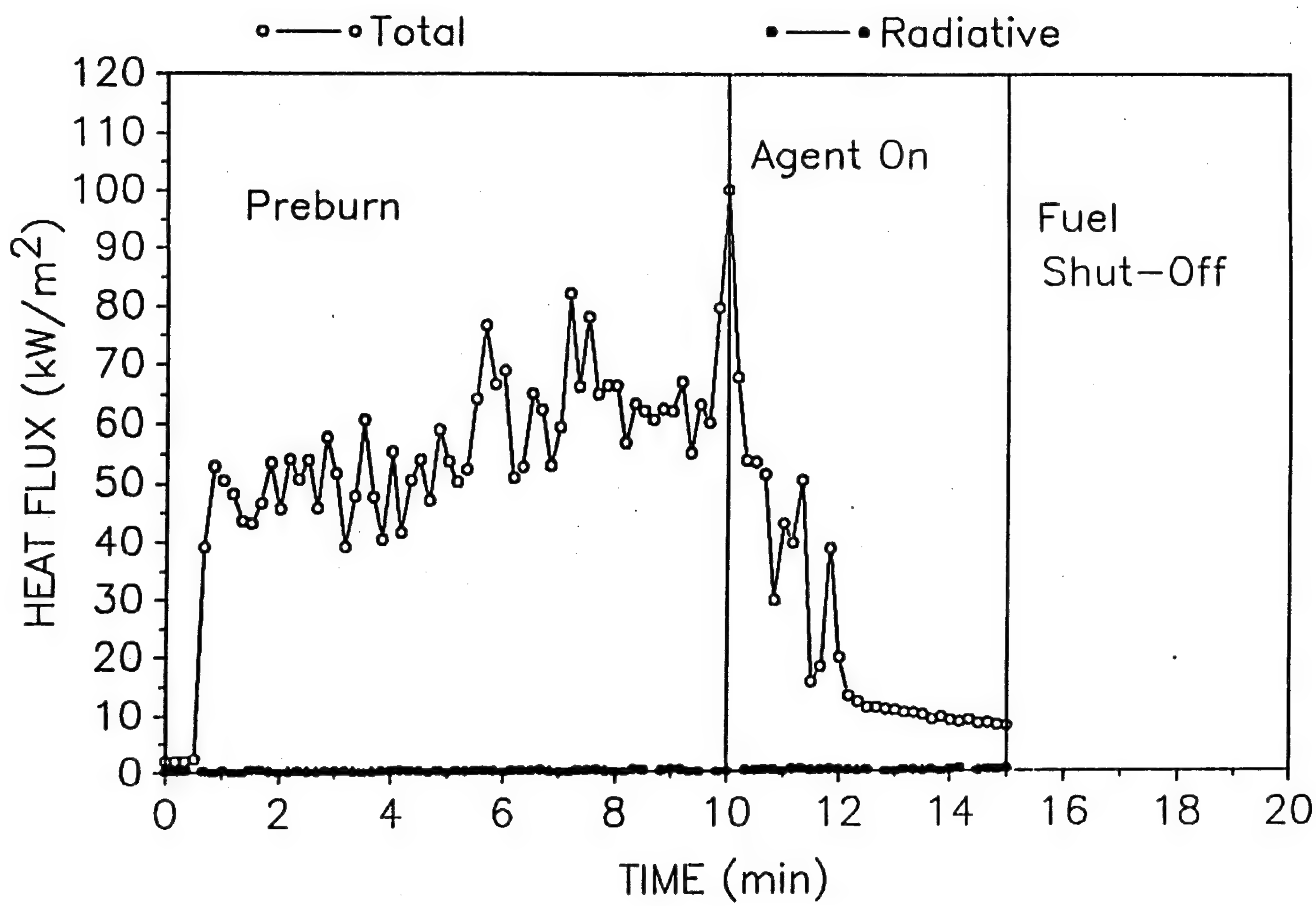

Fig. 30 – Heat flux in east (fire) compartment during test 6

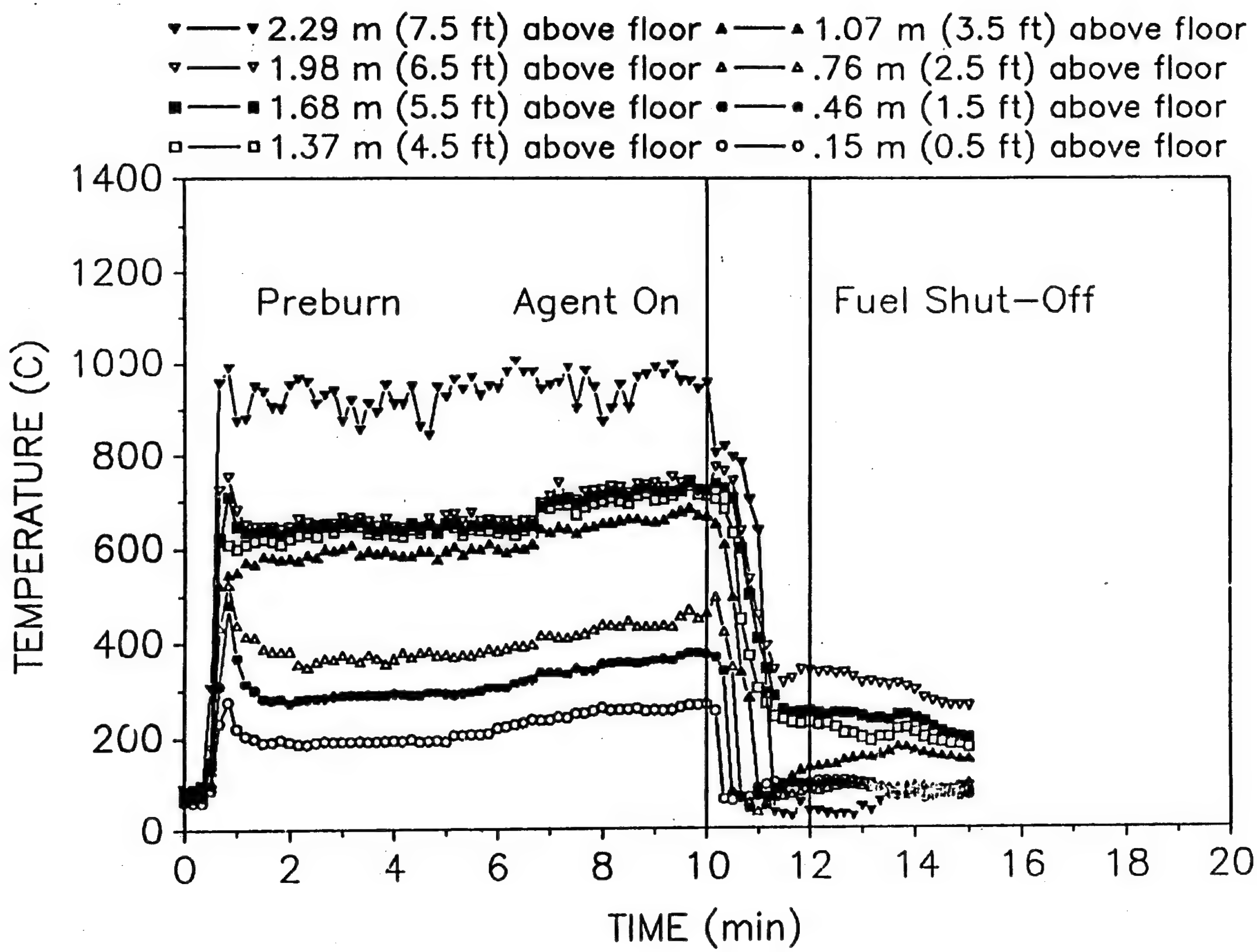

Fig. 31 – East (fire) compartment temperature during test 7

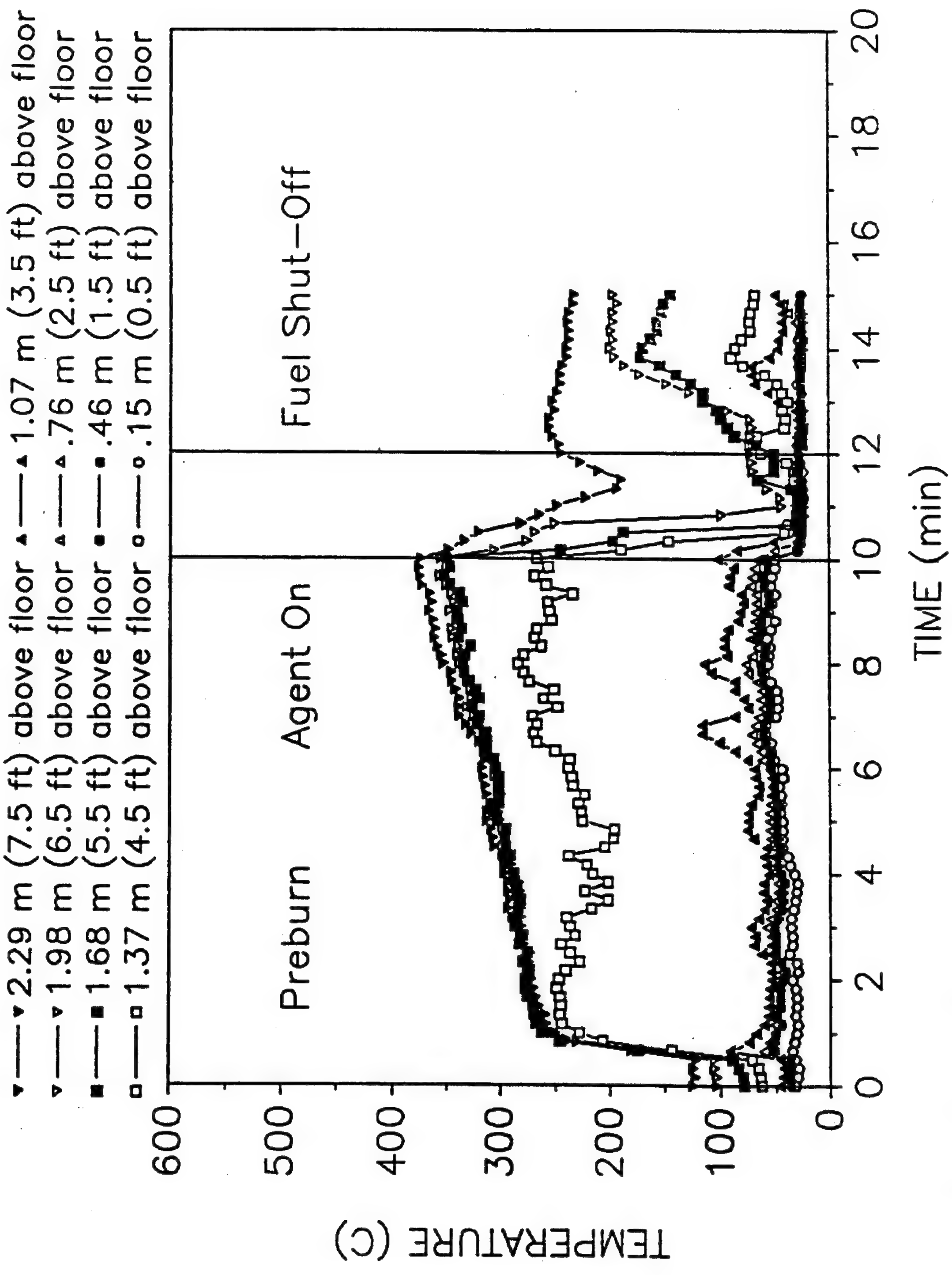

Fig. 32 — Center compartment temperature during test 7

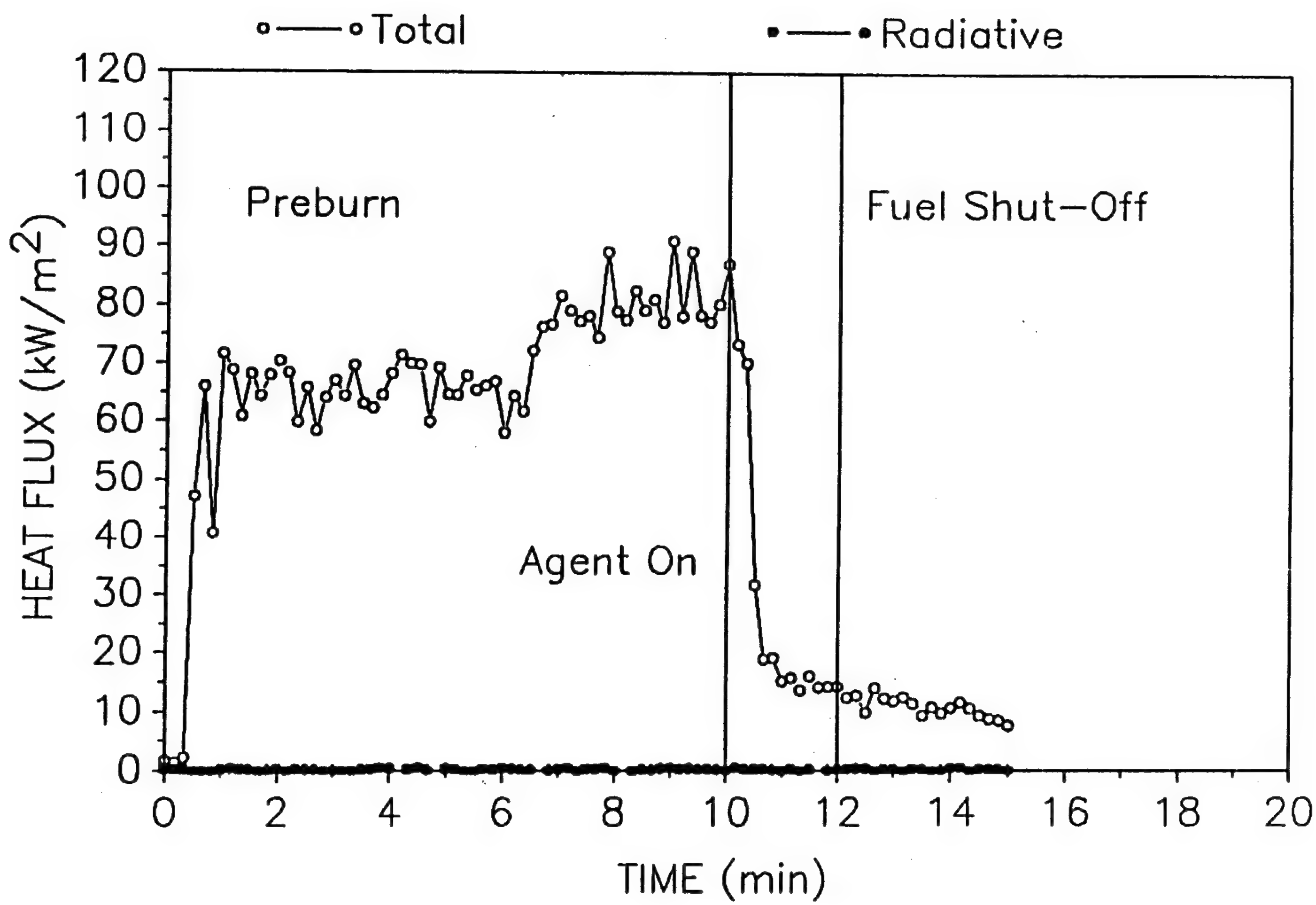

Fig. 33 – Heat flux in east (fire) compartment during test 7

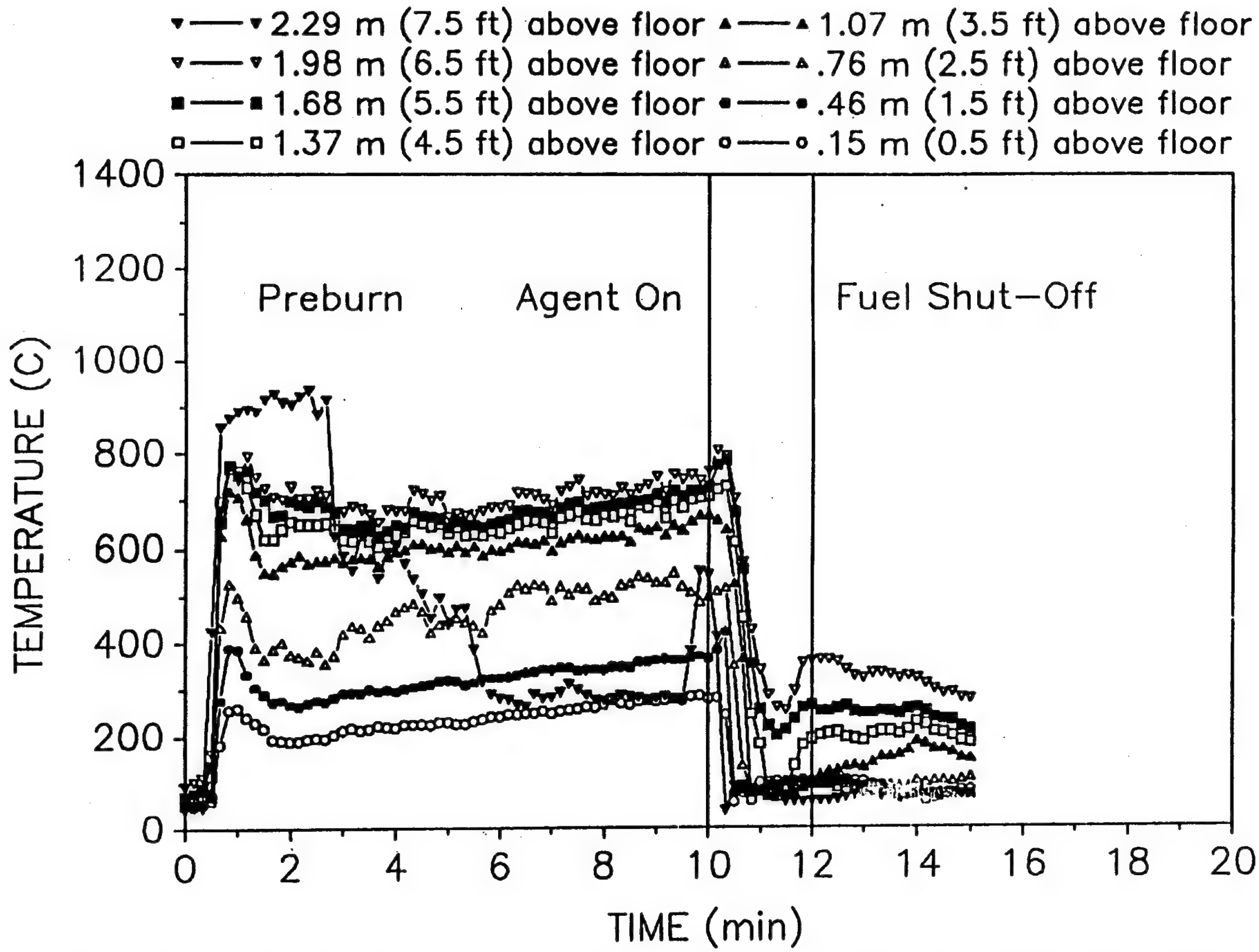

Fig. 34 – East (fire) compartment temperature during test 8

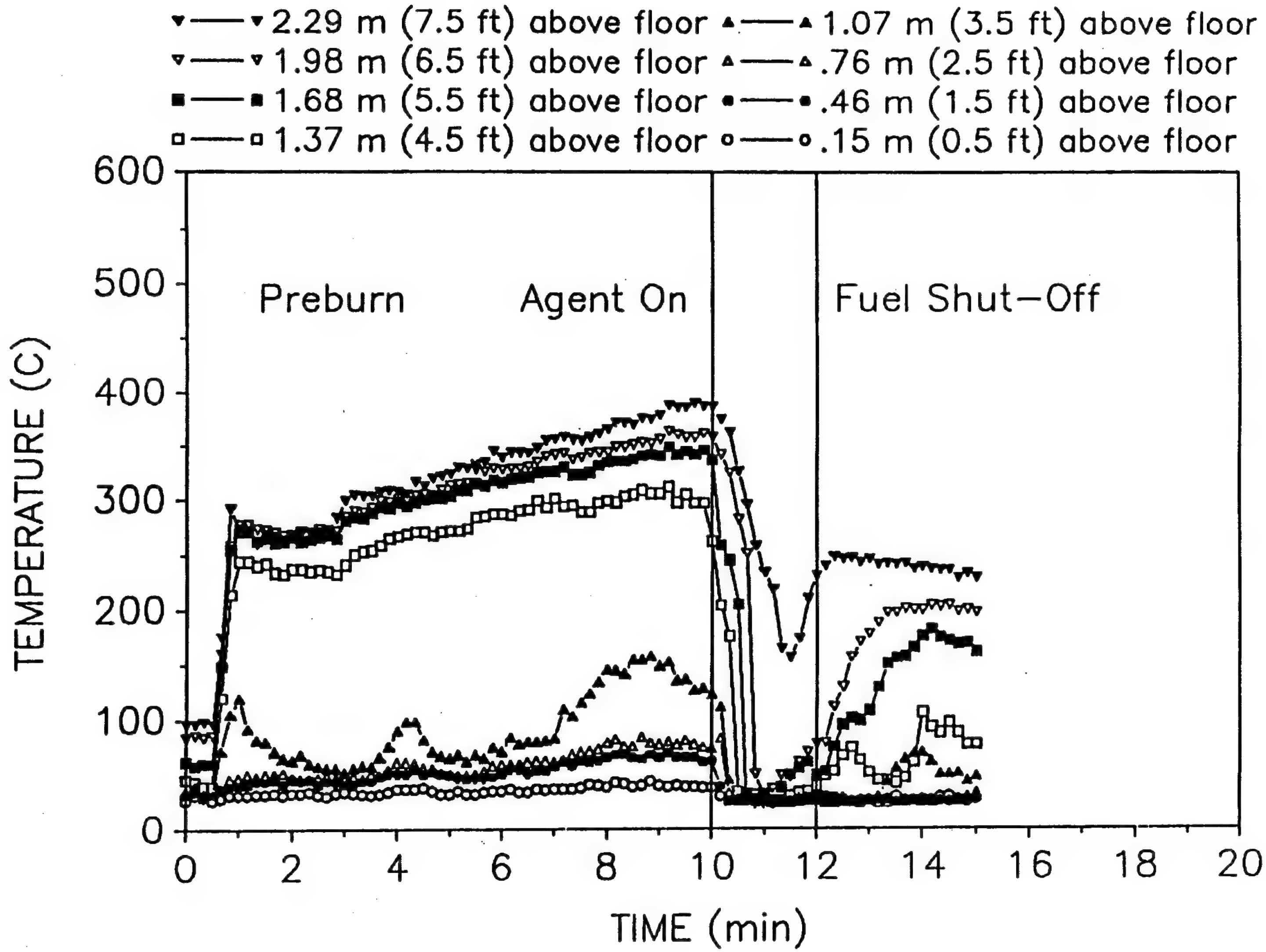

Fig. 35 — Center compartment temperature during test 8

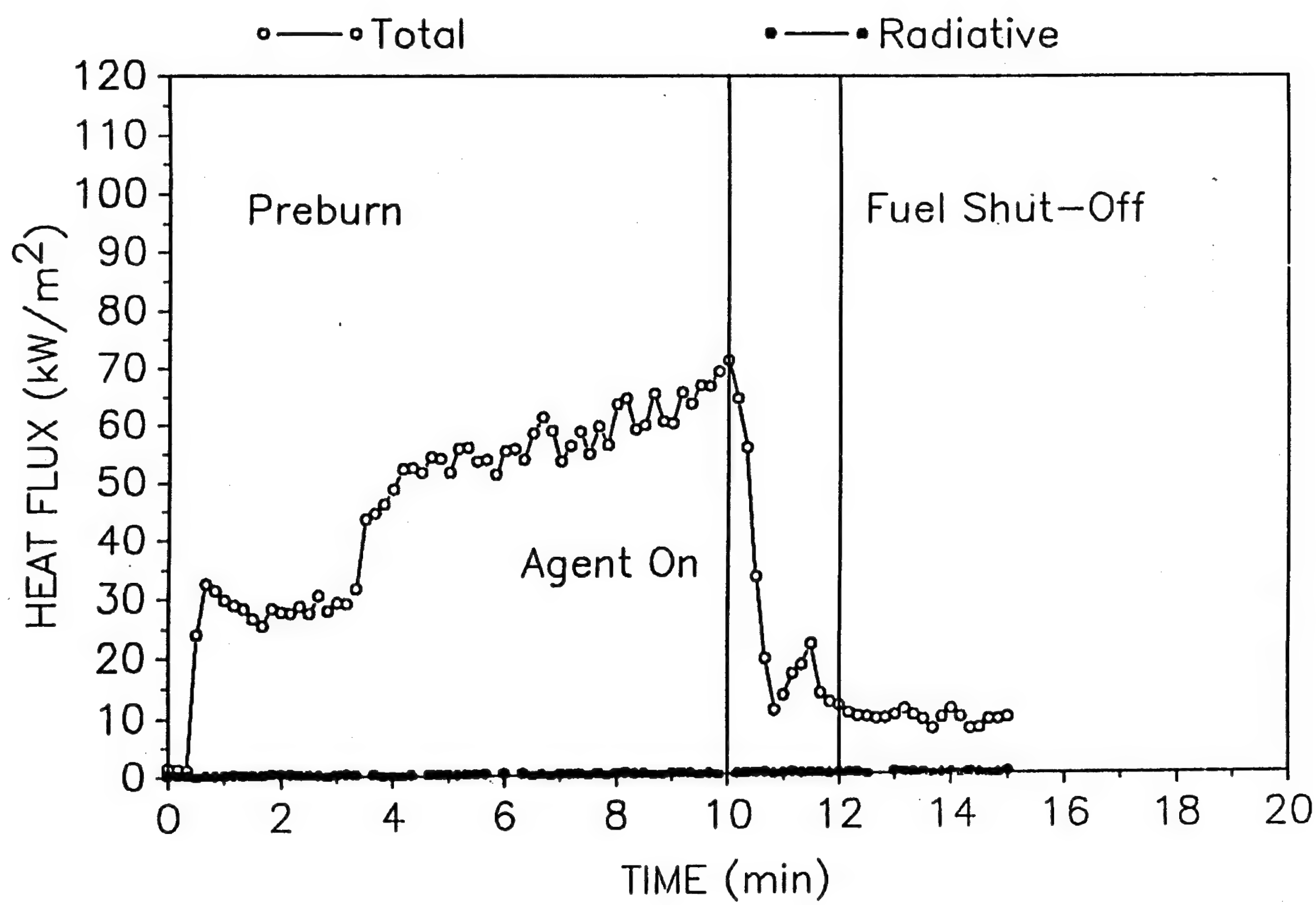

Fig. 36 – Heat flux in east (fire) compartment during test 8

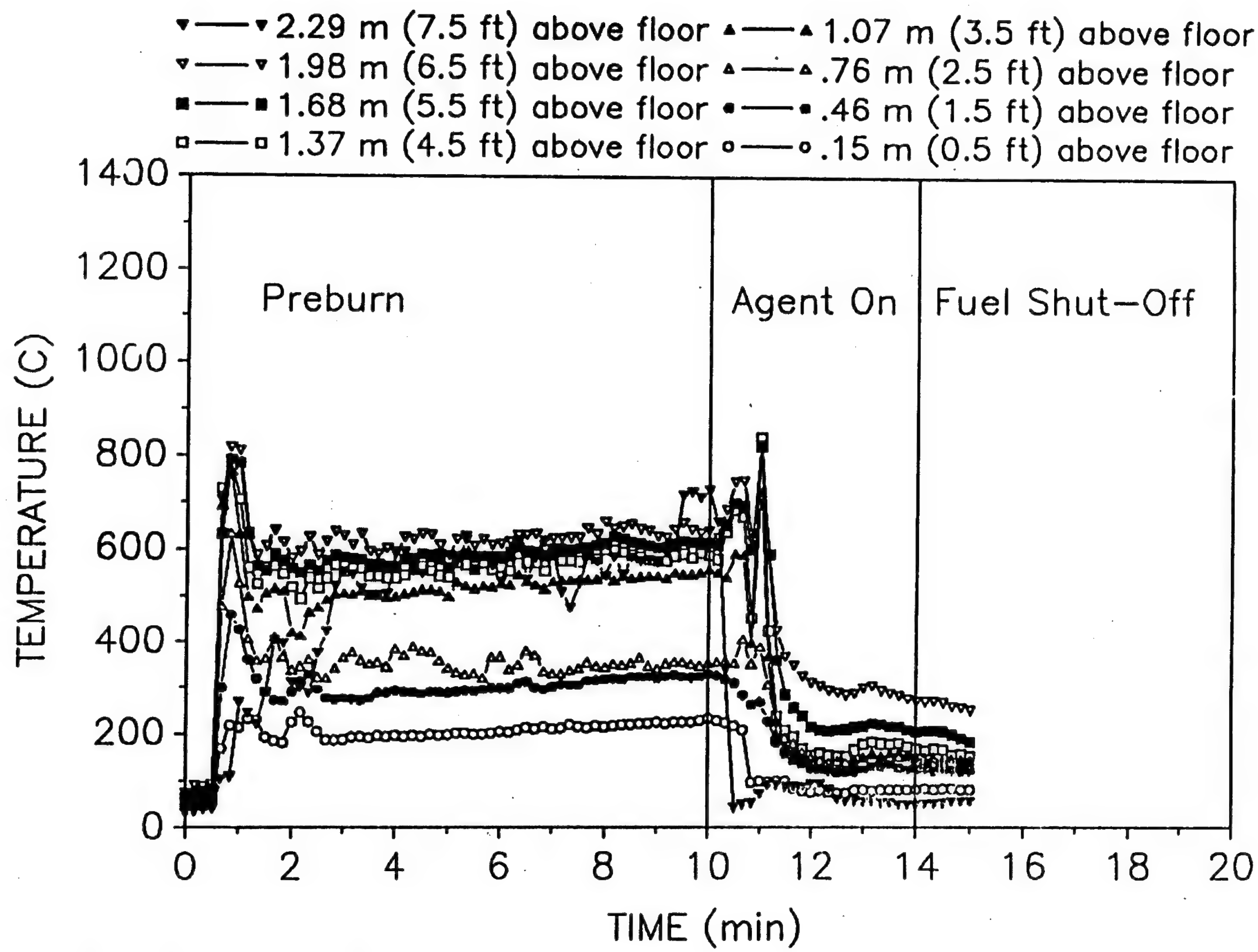

Fig. 37 – East (fire) compartment temperature during test 9

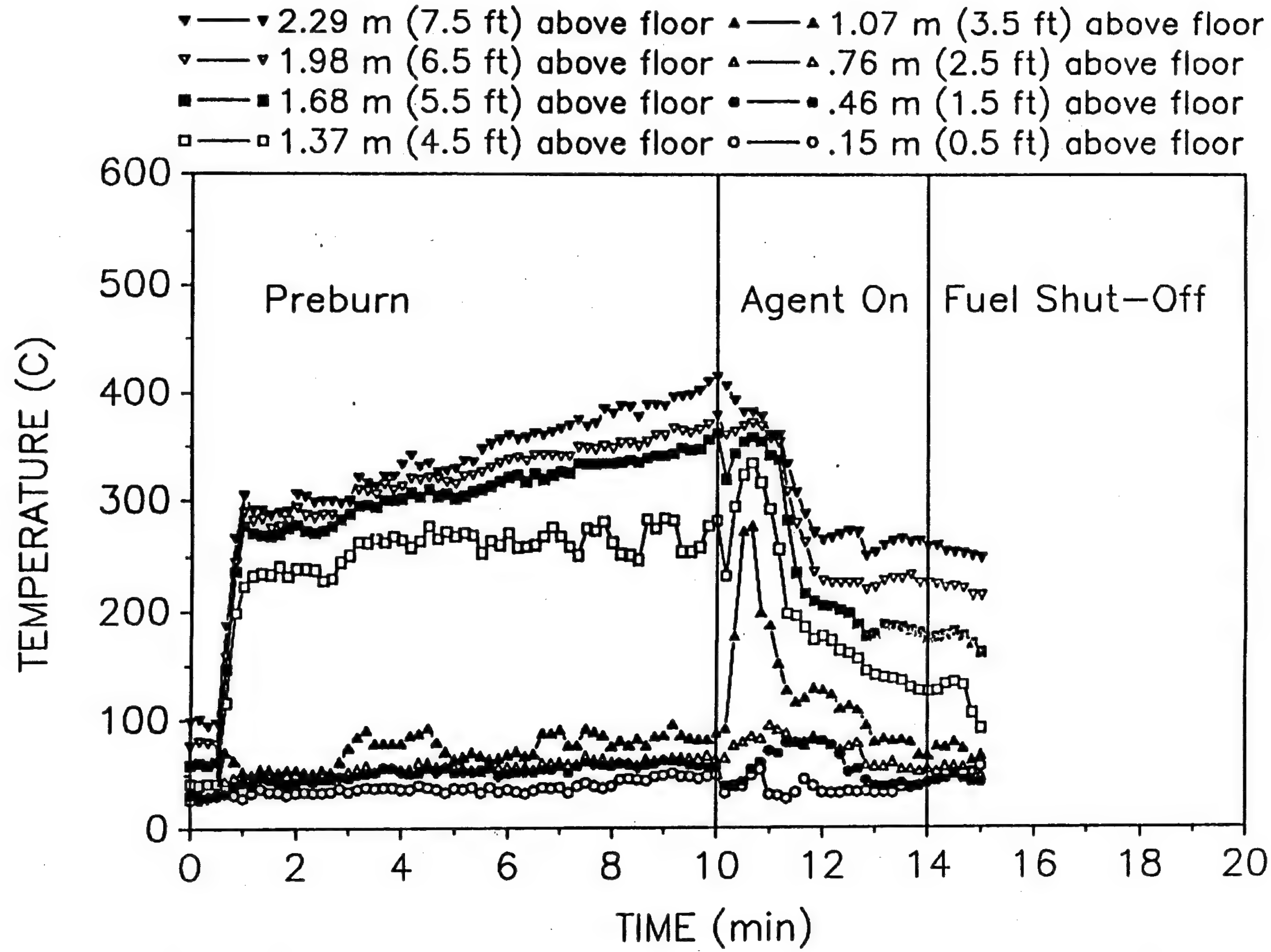

Fig. 38 – Center compartment temperature during test 9

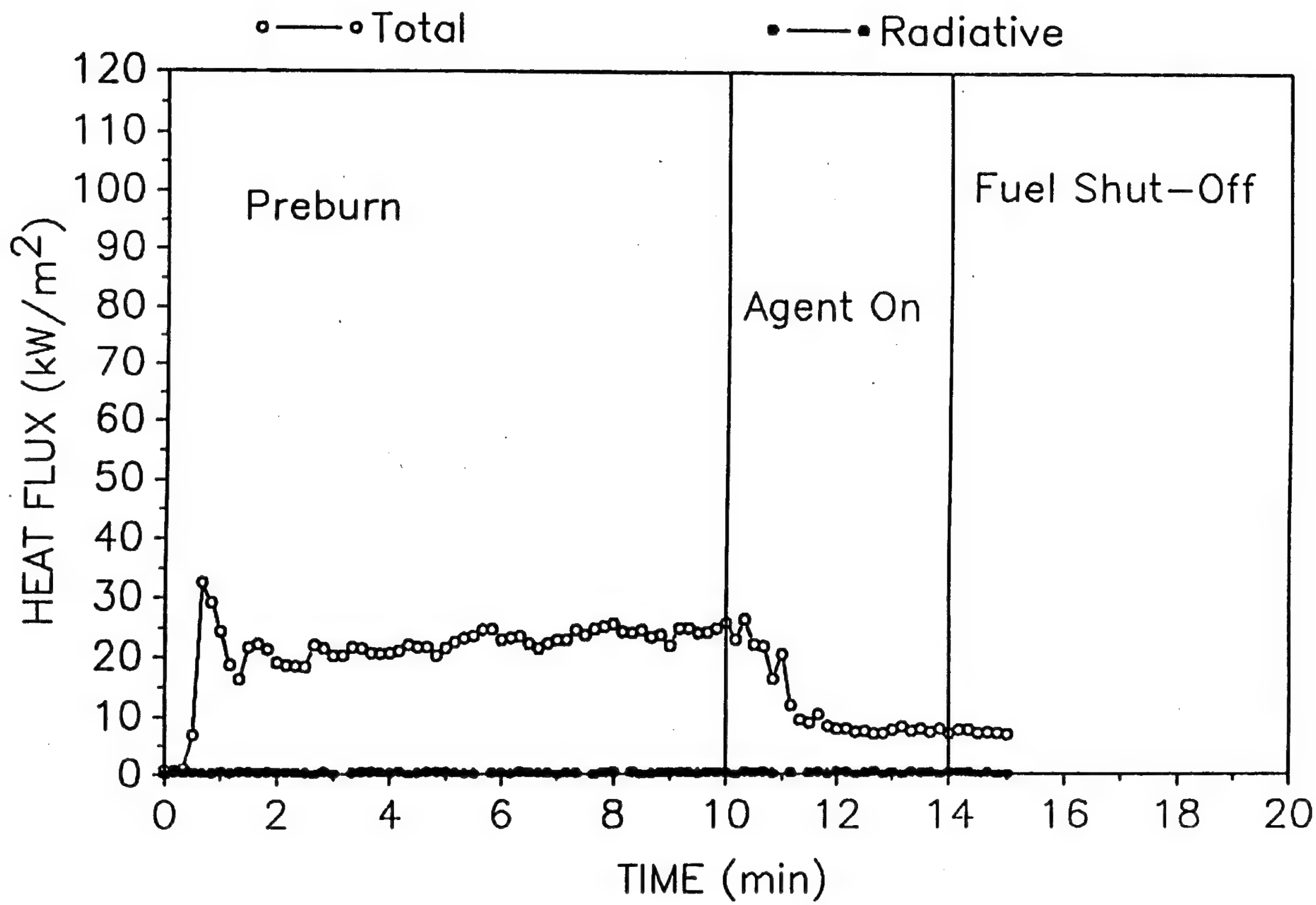

Fig. 39 — Heat flux in east (fire) compartment during test 9

APPENDIX B

Cooling Series Tests

The temperature profile in the center compartment and the surface temperature profile on both sides of the bulkhead separating the east (fire) and center compartments are given for each test in the cooling series in Figures 40 through 43.

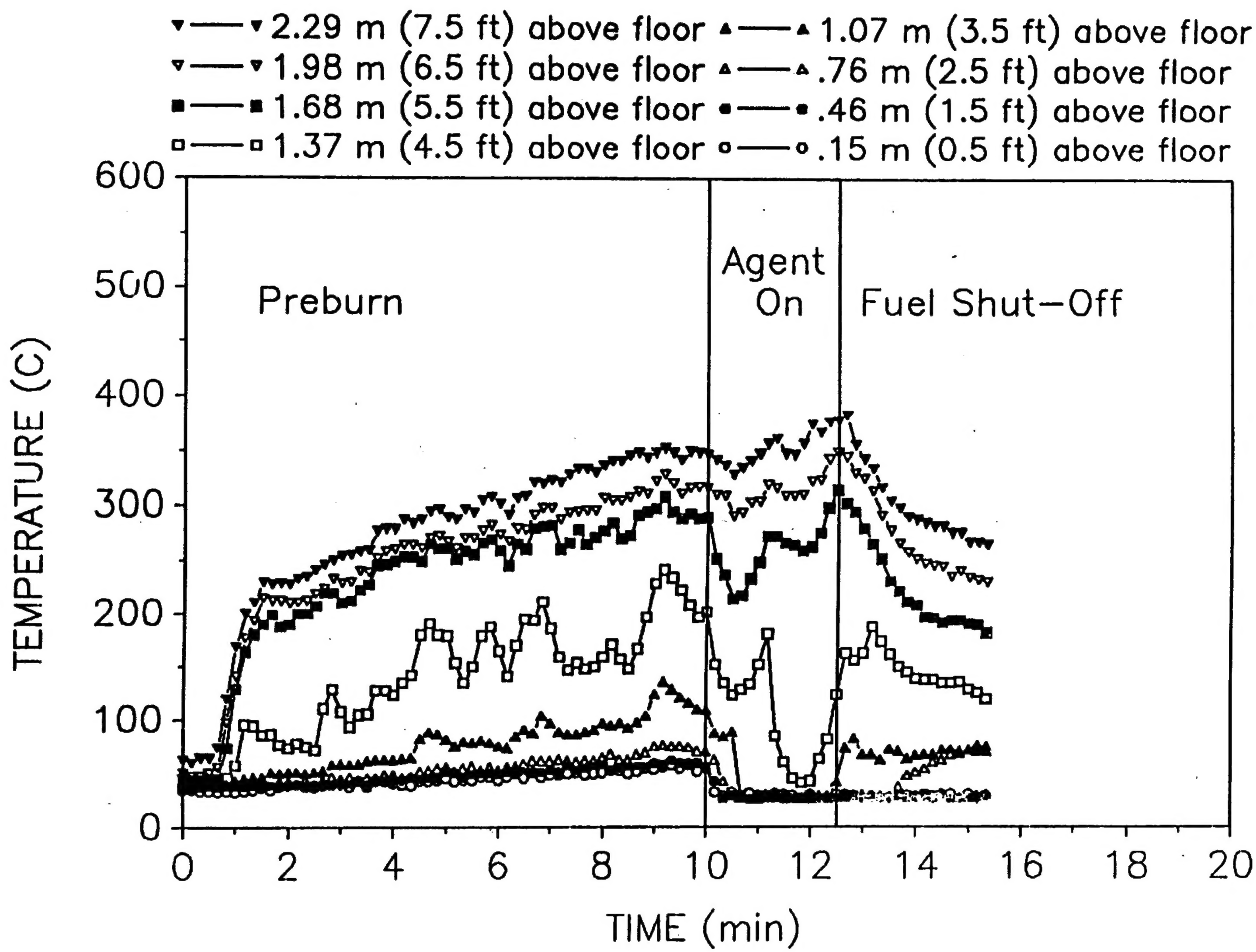

Fig. 40 — Center compartment temperature during test 10

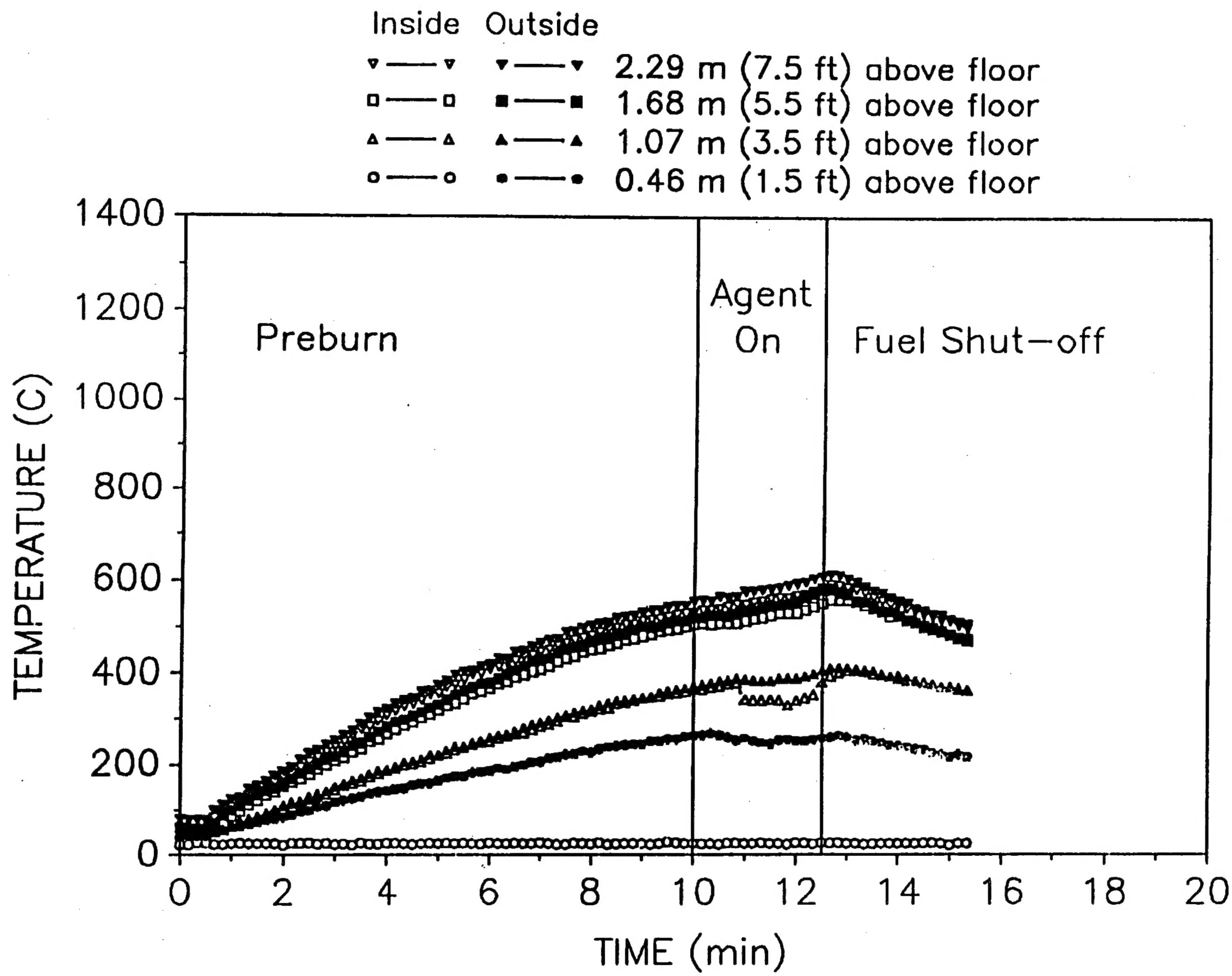

Fig. 41 — Bulkhead temperatures during test 10

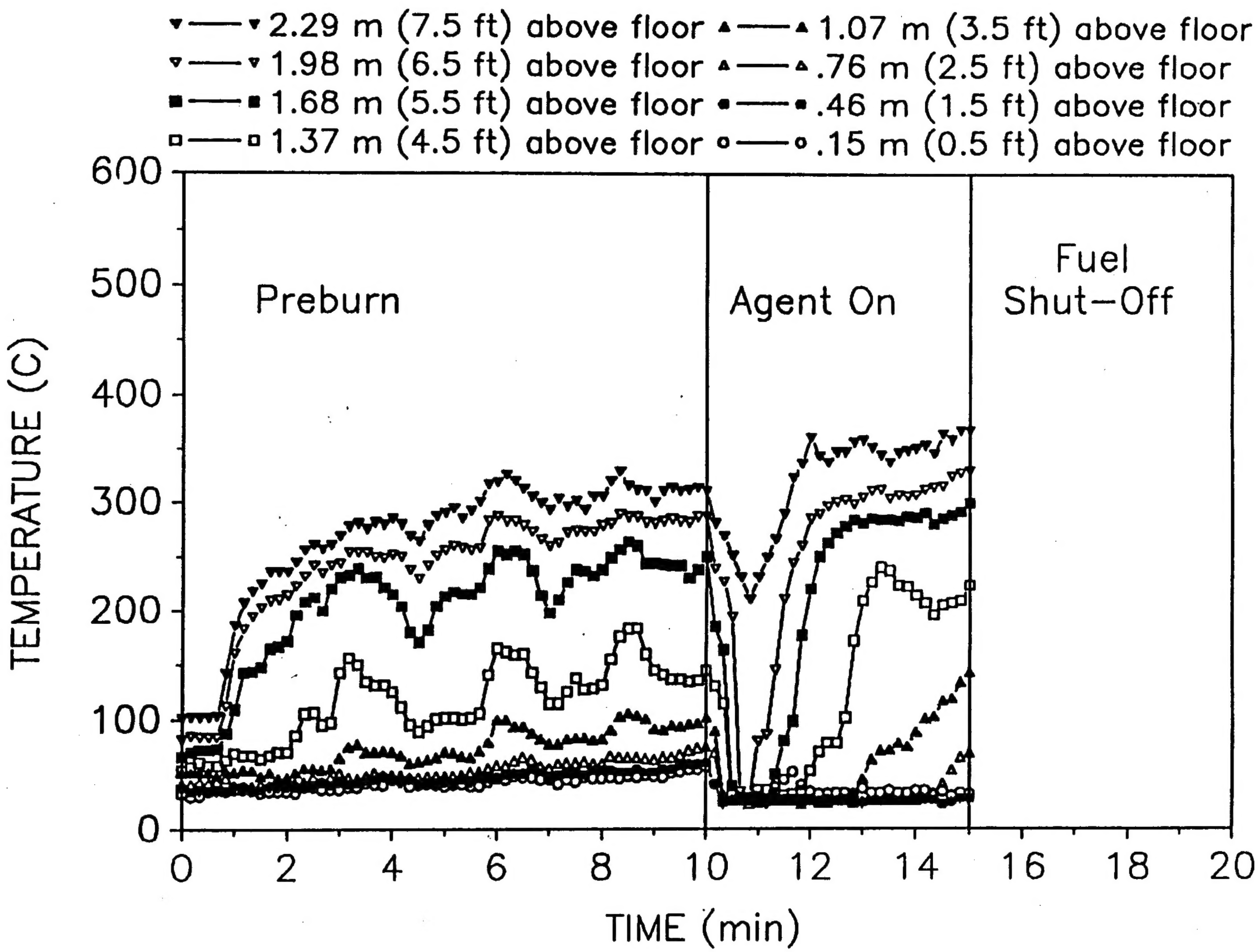

Fig. 42 – Center compartment temperature during test 11

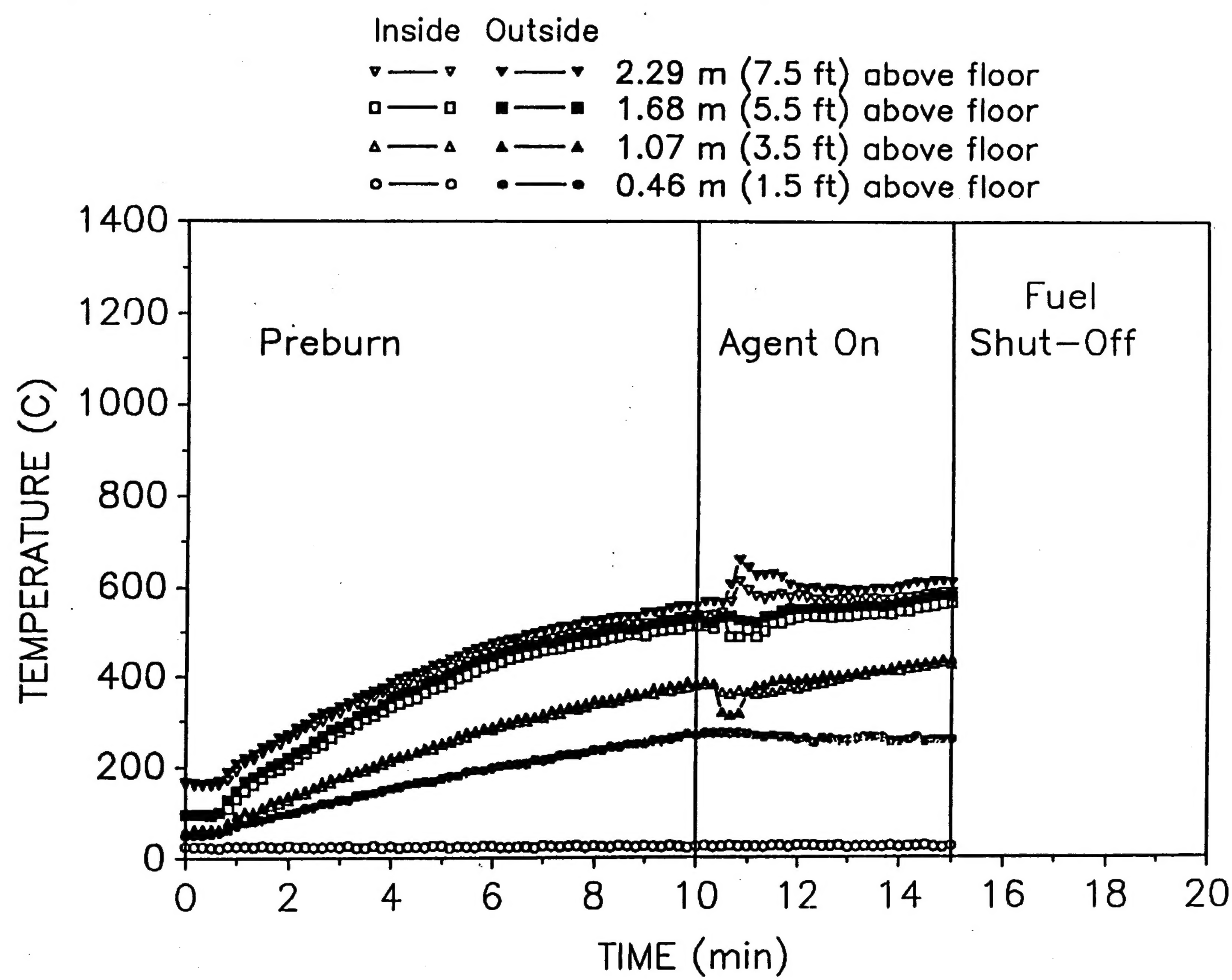

Fig. 43 — Bulkhead temperatures during test 11